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Scott Wilson

Analysis of the Small Parcel Express Carrier Distribution Environment for Drop Height Statistical Referencing and Development of Laboratory Test Specifications

by

Scott E. Wilson

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ABSTRACT

The distribution environment is an ever-changing industry. Test specifications used in laboratory testing to protect product transported through various channels of this environment require constant evaluation. A study to monitor the manual handling of the small parcel express carrier distribution environment was undertaken to quantify the dynamics experienced and better ensure confidence of the parameters for laboratory test specifications. Two package designs, differing in weight and size, were analyzed in 158 trips with and without the use of handholds. Significant drop heights, quantity of drops and orientations of these drops were collected using environmental recorders. The data was analyzed statistically for significance, quantitative distributions and probability of occurrences. Finally, the results were used to develop parameters for two drop tests, an integrity test and a focused simulation test, using only the relevant data collected.

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INTRODUCTION

Although the primary goal of a package is to protect and contain the products to market, the main driving force behind a package design is ultimately cost. Companies are constantly walking the tightrope between cost and protection due to the "cutting of fat" from the package. Because of this continuous focus on cost reduction, products are becoming more susceptible to damage every time a reduction occurs. This is why improved parameters for test specifications and better understanding of the distribution environment is needed for the shipment of fragile products.

Standardized test specifications accepted by the packaging industry have been in place for many years. Testing several hazards found in the distribution environment to simulate actual transportation is known as performance testing.[1] "Standardized procedures for preshipment performance testing of containers were developed in the late 1940s by the National Safe Transit Association (NSTA). Their Preshipment Test Procedures were developed as a means of predetermining probability of safe arrival of packaged products at their destination through the use of tests for simulating shock and stresses normally encountered during handling and transportation."[2]

The ultimate goal of laboratory testing with standardized test procedures is to simulate the dynamics of the distribution environment. By doing so, justification may be

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1 Bakker, 1986.
2 Ibid.

made to support modifications to the current level of protection of the package. Another reason for laboratory testing is to reduce the costs of actual product test shipments in the field. Ship tests of actual product can result to an enormous expense; and offer little confidence the package experiences the severity in handling that others may encounter through similar channels of transportation in the future.

Along with the NSTA standards of the 1940s, many other organizations have developed more recent test standards to be used and accepted across the entire packaging industry. Current organizations such as American Society for Testing and Materials (ASTM), International Safe Transit Association (ISTA), and several others develop standards for the purpose of repeatable testing of packaged product. Repeatability and strong wide-spread acceptance are major features supported within the standards presented by these organizations.

Many large manufacturing companies have gone beyond the boundaries of these organizations to compose their own unique, proprietary standards of testing for their products. Often these independent companies use results of damage returns and customer complaints to estimate the proper testing levels necessary for distribution. These results may not always provide the best answers for protection since customer complaints may be unrealistic or gross understatements of the real damage.[3]

One way to obtain the proper information is to monitor specific channels of the distribution environment. Analyzing the shipping environment and incorporating this information into laboratory test specifications to simulate realistic shipping conditions will provide a more accurate method to evaluate the package design with better understanding

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3 Sheehan, 1988.

of the actual shipping hazards. With this knowledge, packages may be designed to optimize cost and protection.

Within the distribution environment in the United States, several different modes of transportation are used to satisfy various needs for shipment of product. Such modes include truck, rail, air, and water. Because of the different types of handling at the sorting facilities, each of these different modes of transportation has its own unique set of distribution hazards throughout the various segments of the trip. Many of these hazards are listed in Table 1.

Table 1. Mechanical Hazards of the Distribution Environment[1]

Impacts (manual handling)	Vertical	• package dropped to floor during load/unload • package rolled or tipped over to impact a face • fall from chutes or conveyors • result of throwing
	Horizontal	• rail or road vehicle stopping and starting • swinging crane impacts wall, etc. • arrest by stop or other packs on conveyor • arrest when cylindrical package stops rolling • result of throwing
	Stationary package impacted by another	• all of the above where circumstances cause the falling pack to impact another
Vibration (vehicular handling)		• from handling equipment • engine and transmission vibration from road vehicles • running gear - suspension vibration on rail • machinery vibration on ships • engine and aerodynamic vibration on aircraft
Compression		• static stacks in factory, warehouse, store • transient loads during transport in vehicles • compression due to methods of handling • compression due to restraint

1 Bakker, page 244-5.

The drop height levels and quantities of drops for package performance tests can significantly influence design cost. Due to the high forces resulting from drops and tosses, manual handling results in the worst types of damage to the package/product system for packages weighing up to 110 pounds.[4] Therefore, the levels that represent actual distribution hazards must reflect what actually occurs in the environment. If testing levels are too stringent, costs to protect the products are driven higher; conversely, if drop test levels are too low, costly product damage can occur. Many of these unnecessary costs may be avoided by carefully monitoring the distribution environment and developing an accurate performance test based on this data. In fact, ASTM D-4169 specifically states "if more detailed information is available on the transport environment... it is recommended that the... procedure be modified to use such information."[5]

A well-defined test specification must ensure repeatability of the hazards subjected to the package in the test. With a clearly defined test purpose, specific test levels, and explicitly specified methods of performance, repeatability in laboratory tests may be ensured throughout each additional test performance. Test methods are very important in the development of a specification. "Test methods specify and describe acceptable and preferred equipment, sequence of performance of steps in a test, standards for calibration of equipment and instrumentation, and operational recommendations and cautions."[6] The reliability of repeating a test depends upon this section of a specification unequivocally for the purpose of exactness and accuracy of performance.

The test levels established for each test specification provides the integrity of the performance test. The establishment of the test levels directly influence the package design by introducing intensities of hazards to the product/package system. For example, the package protection criterion for a drop height performance test using a drop height of

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4 Bakker, 1986.

5 ASTM, 1996.

6 Young and S.Pierce, 1996.

18 inches rather than 36 inches is significantly different. The package dynamics for a drop test of 36 inches would most definitely damage a product designed specifically to the levels of 18 inches. Significant modifications to the cushion design, carton strength and product ruggedness may be required to adequately protect the product at the much higher impact level.

Although the standards previously mentioned have been very reliable test specifications throughout the broad spectrum and general use forum, actual shipping environments are diverse and complex. Many of the standards used by companies today were developed by committees to protect the packages to a specified level of acceptance for damage. These levels of damage may no longer be seen in the distribution environment due to the continuously improving processes in sorting, handling, and transportation of goods. Further investigation is necessary to ensure the confidence and accuracy of these industry accepted test specifications.

Now is the time to monitor the environment because of the improved accuracy and extreme reliability of the recording devices. Some past techniques and equipment for measuring and analyzing the dynamics of the distribution environment were too subjective and sometimes inaccurate. "If these experiments are to prove worthwhile, they must be designed so information on specific modes of transportation and specific types of handling are [accurately] measured. We may then be able to... identify the drops that inflict the most damage, regardless of their statistical probability."[7]

A few prior focused simulation studies have recently made attempts to capture this information for several different shipping environments. Dennis Young and Stephen

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7 Daniels, 1984.

Pierce monitored the Less-Than-Truckload (LTL) shipping environment, Mark Kerr analyzed the distribution in the small parcel express carrier environment, and S. Paul Singh headed several studies through different channels of the small parcel express carrier environment. Each of these studies proved the handling throughout the transportation environment needs more careful observation and additional data collection. The consensus from these results conflicts with the general use standards accepted throughout the packaging industry. Reasons for this difference may be that these studies were focused simulation tests, rather than general simulations or integrity tests.

Performance testing may be divided into three main categories of classification: integrity testing, general simulation testing, and focused simulation testing. To challenge the package strength and evaluate its overall robustness of design, an integrity test should be used. This does not simulate actual field hazards, but aids in the development of package designs that may be implemented to overcome the harsh dynamics in the environment. Packages that are examined with integrity tests are put through the worst possible scenarios a particular distribution hazard allows, requiring little knowledge of the actual distribution environment to ensure minimal damage to the product. This could result in costly overprotection of the product.

The general simulation tests consist of measurement on a broad range of hazards and non-specific modes of transportation that encompass the entire environment. The tests are designed using the worst possible conditions from a series of hazards in shipping. A particular standard that resembles a general simulation is the ASTM D-4169 procedure of specified sequences of hazard simulating tests.[8]

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[8] Young, 1995.

These two styles of testing are beneficial when evaluating a package for protection through several modes of distribution and numerous hazards related. Yet, when testing specific hazards within a particular segment of the distribution environment, a focused simulation test is more desirable. Focused simulations are specific to a particular type of hazard and environment of observation.[9] "The ultimate target for Focused Simulation is to test for all the hazards that exist, and none of the hazards that don't exist."[10]

Several companies have designed their business to provide a service that manages a large, complex network for distribution of small parcel products in an express environment. These companies collect, sort, transport and distribute individual packages to satisfy quick and efficient delivery to stores and customers. These companies include United Parcel Service (UPS), Federal Express, Airborne Express, United States Postal Service (USPS), and numerous others.

As retail markets continuously change by demanding more competitive products and better service, quicker and more efficient transportation is a must. In addition, many companies have implemented Just-In-Time (JIT) shipping to reduce warehousing and store inventories, which requires fast and efficient product distribution. These express carriers provide this easy method of shipping small quantities to customers rapidly. Since each package must be handled separately throughout the sorting processes of the express carrier system, these carriers are the best source of investigation for this purpose. Hence, this study will encompass only the manual handling through the small parcel express carrier distribution environment.

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9 Young, 1997.
10 Young and C.Pierce, 1992.

Therefore, the purpose of this study is to measure the shock levels experienced throughout the small parcel express carrier distribution environment in terms of drop height, frequency of drops, and the orientations these drops occur. Initially, the results of this study will be used in conjunction with current laboratory test standards as a risk assessment tool. It will also be used to influence package design with the intent to reduce costs without jeopardizing product protection. As future studies are completed on a wide variety of carton size and weight ranges, the ultimate goal is to help create a new set of test specifications based on actual measurements from the field.

In addition to the results from this study, consideration to the abundance of information pertaining to ergonomics for package handling, may help provide better insight to the manual handling through the distribution systems of the express carriers. Many companies have already implemented measures to help provide better working environments for those manually handling packages through distribution. Several measures have even aided in reducing drop height hazards to the products. In a study for IBM, it was found, "most current package performance standards do not adjust for these factors [of ergonomics] in spite of the fact they may prove beneficial in terms of reduced drop height for ergonomically sound designs."[11]

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[11] Daniels, 1984.

1.0. EXPERIMENTAL DESIGN

The purpose of this study is to measure the drop heights, frequency of drops, and their orientations in the small parcel express carrier handling system. The analysis will then be used to compare the dynamics of this distribution environment to the current test specifications used during laboratory testing. In order to properly compile a reasonable data set for the purpose of this study, many factors were considered upon the development for the design of the test procedure. Such test plan characteristics as size, weight and style of the shipping containers were carefully developed, as well as carriers used, routes traveled, and quantity of trips performed.

1.1. Equipment Used

In order to record the drop heights of the packages used in this experiment, two Lansmont Corporation - Dallas Instruments Shock And Vibration Environment Record (SAVER) measuring devices were chosen. These recorders each incorporate a piezoelectric triaxial accelerometer to collect the shocks, four megabytes of memory for the data retention, and an onboard real-time clock. Even though the SAVER devices record actual shocks, vibrations, and climatic conditions, the only data collected for this study is drop related information.

As a shock or drop occurs in the distribution environment, the recorder collects the data, digitizes it, and stores this within its memory. Later the user may download this information to a Windows™-based host computer using the SaverWare (v.1.05) program supplied by Lansmont Corporation. The program uses a proprietary algorithm to calculate the drop height data based on a "zero-g" channel. Using this "zero-g" channel, the software estimates the amount of time the shock experiences this "zero-g time" and correlates the calculation to the actual drop height.[12]

Different types of shock waveforms result from the activity just prior to the actual impact. A freefall drop has a unique style of waveform just prior to the actual shock; tosses and lateral impacts (kicks or bumps) have their own unique styles. These different dynamic types and the significance of each are all explained later in this study located in the Collection and Validity of Data section.

1.2. Selection of Product Package Design

The main interest in this study for the collection of drop data is based on two common product lines of computer printers. For this reason, the two packaged products used directly correlate to the actual box sizes and weights of two existing products. The center of gravity and the weight disbursement throughout the packages were closely analyzed and incorporated into the internal design of the final test package assemblies.

The two packages were void of any type of print, except the shipping labels to eliminate potential special treatment in handling due to the trade dress of the package.

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[12] Lansmont, 1995.

Otherwise, the severity of the manual handling by the small parcel express carriers may have been compromised. By using the plain boxes, the results of the manual handling for the packages could be more realistic in nature. These two existing package sizes are as follows (Note: the use of the word size for the two packages relates to both the dimensional size and the weight of the packages):

- Smaller Package Size: This box style is consistent with that of an Inkjet Printer composed of a C flute singlewall Kraft corrugated RSC with a mass of 14 pounds and dimensional measurements of 19 1/2"L x 12 1/2"W x 15 3/4"H. The center of gravity for the contents is centered about the footprint of the box and closer to the base than the top of the package.

- Larger Package Size: This box style is consistent with that of a Laser Printer composed of a BC flute doublewall Kraft corrugated RSC with a mass of 52 pounds and dimensional measurements of 23 1/4"L x 19 1/4"W x 18"H. The center of gravity is relatively the same as the previous design.

Another parameter implemented in the study was the use and lack of handholds in the packages. Each of the two package sizes stated above were given an added feature to analyze as follows: packages containing handholds, and packages without handholds. This parameter was incorporated to confirm that a package with handholds could be handled with greater ease and endure lower potential drop heights. Therefore, the box lacking handholds would be manually handled by holding the bottom of the container, thus raising the maximum possible drop height. For both of these package sizes, this height difference is close to 13-15 inches. Hence, the four package sizes to be analyzed throughout the study are as follows:

- Smaller package size with the Use of Handholds
- Smaller package size with No Handholds
- Larger package size with the Use of Handholds
- Larger package size with No Handholds

1.3. Test Package Design

The structure of the internal design for both packages is a simplified example of the actual products' relative size and weight disbursement. The fixture which the environmental recorder was anchored is composed of a simple wooden structure with added weights to account for the appropriate mass of the product. These weights consist of thin metal plates that are securely fastened to the wooden structure.

The fixture was cushioned with fabricated foam to prevent the maximum shock from exceeding the limitations of the environmental recording instrument (200 g's) and to center the weight in the container appropriately. In addition, a rugged corrugated spacer was used at the top portion of the package to better represent the center of gravity. The illustrations in Figure A.1 in the Appendix depict the assembly drawings of the actual package systems used in this study.

1.4. Carriers Used

The study of the express carrier distribution environment was chosen over other transportation carriers for several reasons. First, the purpose of the study is to focus on the highest potential for shock damage (i.e. drop heights of packages) throughout transportation. Therefore, carriers that manually handle packages throughout their distribution networks were selected. Since measuring pallet load handling was not a consideration in this study, these carriers presented this benefit. The environment of the

Less-Than-Truckload (LTL) shipments was a consideration, but concern about scheduling of the test shipments became an issue with this method of transportation.

Ease of using the small parcel express carriers was another reason. The test shipments may come and go as needed and do not require special planning or scheduled shipping. The type of sorting performed by each of the small parcel express carriers chosen is different due to the sorting patterns and processes. A desire to monitor the differences between the ground versus air transportation systems provided these different types of sorting processes and aided in the selection of the two carriers. The ground carrier (Carrier G) utilizes a sorting at each individual hub, whereas the air transportation carrier (Carrier A) sorts primarily at a centralized facility.

Prior to beginning the test shipments, careful planning was performed for the correct usage of these carriers. The objective was to get the packages to the destinations and back to the point of origin as efficiently as possible. This was accomplished by supplying, within the outbound test containers, the proper return shipping materials for the "turn-around" person to affix on the top panel of the test cartons. By performing the trips in this manner and sending pre-filled return shipping materials, this reduced the opportunity for errors and sped up the data collection process.

Although the two small parcel express carriers used in this study are aware the distribution environment in which they operate is constantly being measured, they were not informed this particular study was being performed. This was accomplished by shipping the packages in the plain Kraft containers so there was no risk of collecting biased data through special handling. The packages could not be insured, even though the expense of the instruments would be a substantial consequence if they were lost. By insuring them, the individual handling through each hub would be performed by the claims personnel, who would give special treatment to assure the protection of each package as it enters the facility, right on through to its departure, which would have biased the results.

1.5. Routes Taken

Careful consideration to the routes was done by consulting with the express carriers used for the transportation of the actual products. One of the carriers chosen designed a zoning map radiating from the point of origin of Lexington, KY. This information provided the amount of product being shipped to those zones and the amount of damaged product recorded from each of those regions.

After analyzing this information, two destinations of similar zones were implemented into the study. These destinations were contained within the higher quantity shipping status regions and possessed similar claims of damage returns. The first destination tested was Boulder, Colorado and the second Rochester, Minnesota. Both of these destinations were capable of transporting the packages back to the point of origin via the selected return carrier. Another reason for choosing these locations was the reliability in the people involved to turn shipments around in an efficient and expedient manner.

1.6. Quantity of Trips

The final planning procedure for the study was to estimate the amount of trips to be performed for each of the routes, carriers, and box styles. It was agreed that ten round trips for each of the two destinations by the four packages would suffice for a statistically valid study. The amount of trips for the comparisons between different routes results in 80 trips. Similarly, the comparison between different package designs, carriers and handholds each result in 80 trips. However, if significant differences were later found between any of the variables (i.e. significance for handholds when comparing each package size), the quantity of trips for these comparisons would change. For example, if statistical significance was found between the different package sizes with and without handholds, the amount of trips would actually result in 40 trips each package style. 40 trips for the smaller package with handholds, 40 trips for the smaller package without handholds, etc. Table 2 illustrates the complete breakdown of these trips.

Table 2. Matrix of Trips for the Analysis of Each Characteristic.

		Smaller Package Size		**Larger Package Size**	
Routes	Carriers	Handholds	No Handholds	Handholds	No Handholds
Colorado Route	Carrier A	10	10	10	10
	Carrier G	10	10	10	10
Minnesota Route	Carrier A	10	10	10	10
	Carrier G	10	10	10	10

- For the comparison of Package Styles: Smaller Size - 80 trips, Larger Size - 80 trips.
- For the comparison of Carriers: Carrier A - 80 trips, Carrier G - 80 trips.
- For the comparison of Routes: Colorado route - 80 trips, Minnesota route - 80 trips.
- For the comparison of Use of Handholds: With Handholds - 80 trips, Without Handholds - 80 trips.

- Smaller package size: with handholds - 40 trips, without handholds - 40 trips.
- Larger package size: with handholds - 40 trips, without handholds - 40 trips.

To support the breakdown of trips as listed in the table, a statistical formula was introduced to establish the confidence levels based on the number of trips required to best compare the results. Using this formula and dividing the data into four major categories, (i.e. the four package styles), the confidence levels may be found. This formula illustrates the confidence levels of sample size correlated to the upper confidence limit or failure probability. For example, for a 5% upper alpha confidence limit, the ability to collect a 95% confidence level that all the data is correct, requires 59 samples. Using the manipulated Formula 1.6.5 and a 95% confidence limit input, this study calculates to an 87.15% confidence interval with 40 trips for each package design (the two package sizes with and without handholds). This states that the data collected possesses an 87.15% confidence in accuracy. If only one variable shows significance (i.e. just the two package sizes), then 80 trips for each package size may be measured for 95% confidence limit resulting in a 98.35% confidence level that the data collected is accurate.

(1.6.1) $$N = \ln(1-\beta) / \ln(1-\alpha)$$ [13]

where N = Number of samples (i.e. quantity of trips)
β = confidence level
α = upper confidence limit or failure probability

Manipulation to estimate confidence level for a given number of trips:

(1.6.2) $$N = \ln(1-\beta) / \ln(1-\alpha)$$

(1.6.3) $$\ln(1-\beta) = N * \ln(1-\alpha)$$

(1.6.4) $$1 - \beta = e^{N * \ln(1-\alpha)}$$

(1.6.5) $$\beta = 1 - e^{N * \ln(1-\alpha)}$$

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13 Lewis, 1996.

2.0. COLLECTION AND VALIDITY OF DATA

The data was collected on the Lansmont SAVER recording devices as previously stated. Once a shock occurs to the package, the instrument digitizes the data and saves it against an internal real-time clock. The data may later be downloaded to a host computer for analysis where the shocks can be recorded for the type, level, frequency, orientation and time of the drops. By providing the times using an internal clock, matching shock and drop data to handling events is possible. One may now be able to see where the most abusive handling to the products is likely to occur during the transportation cycle. For example, one may correlate the frequencies of drops and drop height levels to an individual sorting facility.

2.1. Analysis Using the Environmental Recorders

Shock analysis was performed by using the software program supplied with the environmental recording devices. To assure confidence in the collected data, all the events recorded were analyzed individually. In addition to the methods of analysis provided within the user manual for the environmental recorder, William Kipp of Lansmont Corporation added insight into other methods of analysis for each waveform. Manual analysis of the waveforms involves moving a cursor about the wave to the accurate location or assuring the accuracy of the provided result. As the cursor moves along the wave, the software recalculates the drop height using the proprietary calculations accordingly.

Laboratory testing also provided better understanding of the data. It was essential to perform laboratory tests, not only to calibrate the accuracy of the devices, but also to investigate some of the indeterminable events recorded. Some of the "real-world" events can be deciphered only by repeatability since, within the "real-world," many events do not simply occur as vertical drops or smooth horizontal tosses. Many of the events that were nearly impossible to determine by observing the waveform became easier to distinguish when laboratory tests confirmed a rotational motion was involved during the drops. Some of these rotational motions were twisting, spinning, and bumps in mid-air.

Through laboratory testing, a correlation between shock G-levels and drop height was established for each package size. This was needed because there were some additional degrees of accuracy required for many shocks. With the results from the laboratory calibration tests, a much greater confidence in accuracy of interpretation for the drop heights was achieved.

2.2. Relevant Data

The data representing freefalls or tosses was compiled for the analysis of the study, while all other impact shocks were excluded from the analysis. Barred information includes data that appears to have been a result of something foreign coming into contact with the package or horizontal impacts that did not resemble a freefall or toss. Lateral impacts and foreign shocks can be useful pieces of data when determining the protection capabilities of particular packaging components in a design. However, they are typically not significant when compared to shocks caused from drops and tosses. Since this study is only testing the drop heights incurred throughout transporatation in the small parcel express environment using a "dummy" test container and not the integrity of a package structure, data that does not resemble a drop is irrelevant.

Additionally, drops or tosses that were less than an 8 g trigger level were also excluded. Most of the shocks below this trigger level were too difficult to distinguish as a drop or toss when analyzing the waveform. Some of these low shocks could have been jostling on a conveyor or bumps in road travel. Whatever the case may have been, it was decided these drops were too insignificant for the results of the study.

3.0. ANALYSIS OF DATA

Through careful analysis of the data, many areas of interest are observed. Some of the steps involved in the analysis are the calculation of drop heights, comparison of the quantity of drops per trip, and observing the orientations these drops occurred. From the 160 total trips throughout the study, two trips were invalidated due to an envirnmental recorder malfunction for the larger package size with handholds during one round-trip. Through the course of the analysis, 1002 freefalls and tosses from these 158 valid trips will be thoroughly investigated for drop height, quantity of drops and drop orientations.

3.1. Significance of Data

The significance of the relevant data collected throughout the study requires careful evaluation. Variables such as the use of handholds, size and weight of the test packages, different carriers involved, and the routes traveled will be compared. If significant differences or interactions between these variables result from any of the comparisons, test parameters to the specification must accommodate the deviations.

The significance of these variables is found by using the Analysis of Variance (ANOVA) method of statistical reasoning. This method of statistical analysis uses several complex calculations to provide one unique result. Figure A.2 demonstrates the usage of the ANOVA method of statistical reasoning as applied in this study. First, the groups or variables must be agreed upon (i.e., style of packages: smaller versus larger package size). The data in this study is classified using the ANOVA method for significance in two independent forms between each variable: the drop heights and the total quantity of drops. The collection of the entire subset of data for each variable is then compiled into the formulas where the calculations illustrate any significant differences between the members of the groups.

For a set of variables to show significance, a comparison of certain values must be evident. For our purposes, the alpha value used for the critical F-distribution is 0.05, representing a 95% confidence test on the data. This alpha value of 0.05 is typically suggested for a study of this nature. The computed F-distribution of the two variables must be greater than the critical F-distribution in order for these two groups to be classified significantly different to each other. Otherwise, there is no significance between the two variables and a single set of test parameters may be used for evaluation in laboratory tests.

3.1.1. Drop Height Significance

Statistical significance is observed within several groups (see Table 3). The comparison between the two package sizes illustrates a profound difference for drop height. Observing the averages for package sizes in Figure B.1 with reference to the sums and counts of the data, the larger size is dropped fewer times, but at higher heights than the smaller package size. This proves there is a definite factor of consideration for package size referring to weight and size during shipment. Similar results show the lack of handholds is treated rougher in manual handling.

Table 3. ANOVA Significance Results for Drop Height Data.

Specified Groups	**Significance by Drop Height**
Smaller package vs. Larger package	YES
Carrier A vs. Carrier G	YES
Colorado Route vs. Minnesota Route	NO
Handholds vs. No Handholds	NO
NOTE: The actual ANOVA calculations are in Appendix Figures B.1.	

The comparison between the two carriers shows a borderline significant difference in the results for drop heights. The rate of delivery by each carrier may be one factor that results in the air carrier receiving several drops at slightly more severe levels. The ground carrier delivered the parcels in two to three days, whereas the air carrier performed this task within one working day. The more careful or less severe handling by the ground carrier sorting process may be due to the advantage of additional time allotted for distribution. This helps explain the variations for the handling between the two carriers. For this reason, the significance between the carriers will not be weighed as heavily as the other groups (i.e., package size and handholds). Nonetheless, this difference will be fully analyzed in later sections.

A further, more in-depth look at the statistical significance must be observed to better illustrate the effects package size, in conjunction with the use or lack of handholds, has on other variables. The ANOVA method is used on the subsets of package size among all the other variables, as well as on the subsets of handholds among all the other variables. Table 4 illustrates the results of the significance between each category for the significance of the drop heights.

Table 4. ANOVA Significance for Drop Height Data
Separated by Package Size and Use of Handholds

	Significance by Drop Height			
	Package Size		Use of Handholds	
	Smaller	Larger	With	Without
Package Size	-	-	**YES**	NO
Carrier	**YES**	NO	NO	**YES**
Route	NO	NO	NO	NO
Handholds	**YES**	NO	-	-
NOTE: The actual ANOVA calculations are in Appendix Figures B.2 - B.3.				

Some interesting conclusions may be derived from these results. Drop heights for the smaller package size were significantly different when comparing the use of handholds, but the larger package did not show any significance. For the results pertaining to the carriers, the smaller package with no handholds showed a significance, illustrating one carrier provided a rougher environment dependent upon package size and the use of handholds. As mentioned previously, this may be due to the handling differences resulting from the allotted time for delivery between the two carriers. However, this may be a result of the smaller package without handholds being lighter in weight and easier to toss around. One carrier may also have more opportunities to handle the packages rougher through the differences in the sorting processes between the two carriers. The routes, however, illustrated no statistical difference for any of the combinations.

Because the larger package size does not reflect any significance for the various parameters represented, illustrations of the results for significance will be used to express the relationship interactions between the variables. The interactions of the statistical significance is found by utilizing the averages calculated from the ANOVA tables in Figures B.2 and B.3. Similar variables are interactive if the slopes of the graphed values are unequal (i.e. not parallel).[14] Additional information may be obtained by observing the differences in the average drop heights to find where significant differences may be found. Significance for drop height through these interactions is illustrated in Figure B.4.

The comparisons of the interactions for the drop heights do show interactive results. In the top table and graph (Figure B.4), the handholds represent a significance due to the two differing slopes. This shows handholds has an effect on the package size for the smaller carton, but not much effect for the larger package size. Even though the comparison for the carriers illustrates similar slopes, the lines are quite a distance apart showing a higher average drop height for the air carrier. The results for the routes are fairly close to one another with relatively similar slopes, hence this is not a significant variable related to package size for drop heights. The overall observation of this graph states the larger package size is consistently higher in average drop height for all variables of consideration, contrary to many beliefs that the heavier and larger a package, the lower the drop height.

Looking at the bottom table and graph from Figure B.4, the two package designs reflect an interaction to drop height. This is expected since the average drop heights for the larger package is higher, as previously seen in the top table. The routes and carriers

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14 Miller and Freund, 1977.

show a slight interaction with the presence of handholds. This suggests that packages without handholds are handled rougher than those with handholds. This is true for the entire summation of the graph; the packages without handholds are consistently dropped higher than when handholds are introduced into the package design.

The routes and carriers do not affect the results enough to justify an individual set of test parameters for development of a specification. However, these results must be looked at closer in each of the following sections to qualify their potential to affect drop heights, quantities and orientations. The two variables that do interact with drop height are the package sizes and the use of handholds. These will be carefully observed throughout the rest of the analysis.

3.1.2. Quantity of Drops Significance

The quantity of drops information is also compared for statistical significance as illustrated in Table 5. The number of drops for the package sizes and the use of handholds showed a significant difference. From the results in Figure B.5., packages without handholds are dropped nearly 100 times more frequently than the packages that introduced these features. This data strongly supports incorporating handholds into packages to reduce potential damage due to multiple drops. This information could be used as a consideration by the packaging engineer for the modification of the package design to support cost reduction justification. However, before any final decisions may be produced, the intensities and orientations of these drops should be considered. The results of the routes and carriers showed no differences for the quantity of drops.

Table 5. ANOVA Significance Results for Quantity of Drops Data

Specified Groups	**Significance by Quantity of Drops**
Smaller package size vs. Larger package size	YES
Carrier A vs. Carrier G	NO
Colorado Route vs. Minnesota Route	NO
Handholds vs. No Handholds	YES
NOTE: The actual ANOVA calculations are in Appendix Figures B.5.	

Breaking the data down a little further revealed similar, but more precise results. Table 6 shows the Quantity of Drops Significance for the study. Both package sizes showed significant differences with the use and lack of handholds, however, only the smaller carton illustrated this significance for the presence of handholds. This demonstrates confusing results for the larger package size because it is not affected by the use of handholds. Additionally, the carriers and the routes illustrate extremely little significance with the quantity of drops for both package size and use of handholds.

Table 6. ANOVA Significance for Quantity of Drops Data
Separated by Package Size and Use of Handholds

	Significance by Quantity of Drops			
	Package Size		Use of Handholds	
	Smaller	Larger	With	Without
Package Size	-	-	**YES**	**YES**
Carrier	NO	NO	NO	NO
Route	NO	NO	NO	NO
Handholds	**YES**	NO	-	-
NOTE: The actual ANOVA calculations are in Appendix Figures B.6 - B.7.				

Interactions for the Quantity of Drops Significance is illustrated in the Appendix as Figure B.8. These two graphs illustrate the differences between the different package sizes and the use of handholds, but show very little interactions for the carriers and routes. Contrary to the drop height results, the smaller package size reflects higher quantities of drops for every variable compared to the larger package size. This means the smaller carton is dropped more times throughout the entire journey. Similarly, the packages without handholds shows higher average drops. The confusing results of the larger package are illustrated in the top graph where every variable is treated nearly identical for the number of drops as evidenced by the cluster of data points around the 5 - 5.2 average number of drops.

3.2. Drop Height Data Analysis

A couple of methods to compare the data for drop heights were considered. The first method contemplated was the Extreme Value Analysis where only the highest drop for each trip is analyzed. This was soon discarded due to a serious conflict that arose during investigation of the data. Several trips included numerous drops at rather high heights presenting a scenario of multiple drops at critical heights. Using the Extreme Value Analysis method would eliminate the possibility of any repetitive crucial drops for a package during one trip, thus neglecting possible or certain product damage to occur.

The method of choice is to analyze the entire data set by examining the summary of the number of occurrences at each drop height. After charting all the data points to the proper drop heights, a cumulative percentage is calculated for each height. This represents the amount of drops at or below each individual height. For example, if 90% on the cumulative distribution curve is correlated to a drop height of 21 inches, then 90% of all drops for this package will be at or below a height of 21 inches.

Since the two package sizes are significantly different for drop height, a comparison between these is illustrated in Table 7 and on the charts located in the Appendix Figure C.1. The smaller package size shows a greater quantity of low drop heights (3"-12") than the larger package size, but approximately the same number of higher drops (12"-30"+). Even though this difference is evident in the charts, the results for the cumulative percentages between the two package designs are very similar. This parallelism would result in the two package sizes incorporating the same parameters for drop heights throughout the developed specification from data in this study.

Table 7. Drop Height Equivalents for Each Cumulative Frequency

Cumulative %	**Smaller Package Size**	**Larger Package Size**
Mean (50%)	7 inches	8 inches
75%	10 inches	12 inches
90%	15 inches	16 inches
95%	18 inches	19 inches
99%	28 inches	26 inches
Max (100%)	39 inches	36 inches

However, if we added the feature of handholds into the analysis and compared the cumulative frequencies as summarized in Table 8, the results are much different. As expected, the smaller package size without handholds has a much higher drop height than packages with them. The handholds are placed approximately 15 inches from the base of the carton. Comparing the presence of handholds on this package size for the 99% and maximum levels, the difference in the drop height is approximately 15 inches. The data proves there is a direct relationship between the use of handholds and drop heights of test packages for the smaller size (see Figure C.2). Even though it may be tossed around easier due the smaller size and lighter weight, the data shows that the use of handholds for the smaller package size is treated with more care. It is generally placed down to a lower height before release. Hence, the use of handholds for this package size should be very beneficial to the protection of the product and potential design modification opportunities to assist in reducing the overall package costs.

Table 8. Drop Height Equivalents for Each Cumulative Frequency Separated by Package Size and Use of Handholds

Cumulative Percentage	Smaller Package Size		Larger Package Size	
	Handholds	No Handholds	Handholds	No Handholds
Mean (50%)	7 inches	7 inches	8 inches	8 inches
75%	10 inches	10 inches	12 inches	12 inches
90%	15 inches	16 inches	16 inches	16 inches
95%	16 inches	22 inches	19 inches	18 inches
99%	20 inches	34 inches	26 inches	26 inches
Max (100%)	25 inches	39 inches	32 inches	36 inches

The larger size, on the other hand, is not significantly affected by the use or lack of handholds. Notice in both Table 8 and Figure C.2; there is little distinguishable difference between the presence of handholds in the larger package size. These results lead to much confusion and must be carefully analyzed further to better understand the differences between the two larger package designs and the dynamics imposed upon each. In theory, the use of handholds should benefit the larger package size more through greater ease of handling. The mere fact that the package is naturally very awkward to manipulate due to its size and weight should support this theory.

In Table 9, comparisons are made using the groups carriers and use of handholds to help further explain the disparities of implementing handholds into the package design. It is hoped that the indeterminable results from the larger package size with the use of handholds may be answered by the differences in handling processes of one particular carrier. However, this additional information reflects very little insight to the larger size as it illustrates similar handling for both the use and lack of handholds among the two carriers. There is a slight distinction with handholds for Carrier A, but there is not much contrast for Carrier G. Extracting some of the data from the study, only 5 drops are above the 25 inch (99% AL) drop height for this size. These drops all range evenly among each carrier for use and lack of handholds. This may be due to the variations between the sorting processes for the carriers, but it still leaves open any explanation for the larger package lacking significance by drop height for the use of handholds.

Referring to the "New Approaches to Defining the Distribution Environment," the package design ergonomics may help to explain why there is not a noticeable contrariety in drop height for the larger package size using the features of handholds. This lack of difference pertaining to the drop heights for packages with or without handholds may be a result of a weight or size issue involving the ergonomics of the package design. The box is dropped from a height equivalent to a person carrying the package by the handholds. It is possible that the carton without handholds is handled by squeezing the sides of the package at the opposite top and bottom corners or opposite vertical edges. The package is then dropped in a manner with very little bending performed by the sorter prior to release of the package. Another possible method of handling may involve the sorter to crouch his/her body to lift the carton from the base, but only enough to move the package across to the desired location. Therefore, one viewpoint to this phenomenon may be the size and weight of this design offsets the benefit of the handholds from having a significant effect on the drop heights in the express carrier shipping environment.

Table 9. Drop Height Equivalents for Each Cumulative Frequency Separated by Package Size, Use of Handholds, and Carrier.

Smaller Package Size				
Cumulative Percentages	Handholds		No Handholds	
	Carrier A	Carrier G	Carrier A	Carrier G
Mean (50%)	7 inches	7 inches	7 inches	7 inches
75%	10 inches	10 inches	12 inches	10 inches
90%	15 inches	14 inches	17 inches	13 inches
95%	17 inches	16 inches	24 inches	18 inches
99%	20 inches	18 inches	34 inches	34 inches
Max (100%)	25 inches	25 inches	37 inches	39 inches
Larger Package Size				
Cumulative Percentages	Handholds		No Handholds	
	Carrier A	Carrier G	Carrier A	Carrier G
Mean (50%)	8 inches	8 inches	9 inches	8 inches
75%	12 inches	11 inches	13 inches	12 inches
90%	16 inches	15 inches	16 inches	16 inches
95%	22 inches	16 inches	21 inches	17 inches
99%	26 inches	24 inches	26 inches	25 inches
Max (100%)	26 inches	32 inches	31 inches	36 inches

Lastly, looking at the charts for the other two variables, it is quite evident why there is little variance among the carriers or routes (see Figure C.3). Even though the carriers demonstrate a significant difference by the ANOVA method of statistical reasoning, there is not enough of a flux to assume a separate set of parameters necessary.

Likewise, the comparison of drop height by routes also reinforces the insignificance between different routes during shipment.

3.3. Quantity of Drops Data Analysis

The quantity of drops experienced by a package explains several different things. A package that is dropped only once needs less protective packaging than another that is dropped several times at similar heights. Likewise, it may be determined that a particular carrier, route or sorting facility supports harsher handling by the amount of drops it forces upon a package during distribution. In addition, understanding the quantity of drops a carton must endure throughout the entire journey will determine the package design parameters.

The amount of drops for each trip is compiled into the frequency of drops using the entire set of values and their cumulative distributions for the different variables. The two unique package sizes are compared using only the features of handholds because these two separate variables are the only two that support a significant difference by the ANOVA statistical method. Carriers and routes did not illustrate any significance to the handling of the packages for the analysis of the quantity of drops.

The results from the charts in Figure C.4 show the amount of trips that experienced a particular quantity of drops per trip for each of the four package designs. For example, the smaller package size with handholds resulted in 7 trips that experienced 4 drops per trip, 5 trips with 5 drops per trip, 4 trips with 6 drops per trip, etc. The average quantity of drops for the smaller package is calculated at 8-9 drops per trip and ranges from 2 to 14 drops each journey. However, the larger size averages around 5 drops per trip and ranges from 1 to 10 drops. This is a very noticeable imbalance that needs further review.

A compilation of the results for the quantity of drops for the use of handholds and package sizes are illustrated in Table 10. The results depict a noticeable difference between the use and lack of handholds for the smaller package size. Separate test parameters may be required for this size when implementing handholds into the carton. Packages lacking handholds are treated with more abuse, hence the handler may more frequently toss the carton rather than place it down gently. As noted in the Drop Height section, this may result directly from the smaller size and lighter weight of this package design.

Table 10. Quantity of Drops per Trip Equivalents for Each Cumulative Frequency

Cumulative Percentage	**Smaller Package Size**		**Larger Package Size**	
	Handholds	No Handholds	Handholds	No Handholds
Mean (50%)	7 drops	8 drops	5 drops	4 drops
75%	8 drops	10 drops	6 drops	6 drops
90%	9 drops	12 drops	9 drops	8 drops
95%	10 drops	14 drops	9 drops	9 drops
99%	11 drops	14 drops	10 drops	9 drops

Similar to the puzzling results from the Drop Height section, the results here continue to show the larger size is not affected by the use or lack of handholds for the quantity of drops incurred. The confusing question again emerges for the larger package size: Why does the use of handholds not have a positive effect in reducing the drop height of this package? One reason may be the large, bulky size and heavier weight of the package is too difficult to handle for a common sorter to manage carefully. Further investigation into the actual handling of these package designs and more review into the science of ergonomics may be necessary to produce solid conclusions about the differences, or lack of differences, for the manual handling of these cartons.

3.4. Drop Orientation Data Analysis

The orientations of drops for the packages are significant factors and must be thoroughly observed. A package test specification contains the drop height and quantity of drops that are recommended for the laboratory test, but without proper knowledge of the corresponding drop orientations, the technician has no idea which face, edge or corner the impacts should be tested. Hence, the orientation of impact for each drop is compiled and analyzed throughout the entire study.

The abbreviations used on the orientation tables and charts are stated below. Other abbreviations are used when illustrating a corner or an edge by simply combining the faces adjacent to the proper axis. For example, BFR is a bottom-front-right corner of the box and KL is a back-left vertical edge. All possible axes are included on the tables for analysis.

B - bottom	F - front	K - back
L - left	R - right	T - top

Since the test packages were plain Kraft corrugated cartons without print, except that of the shipping labels, some assumptions can be made. The orientation for the top of the box is obvious since the shipping labels are located on this face; therefore the bottom of the package is also quite evident. The left and right panels are the two smaller opposite vertical panels containing the handholds, while the front and back panels of the box are the two larger opposite vertical panels. The front and back panels of the carton are not of any significance from one another due to the lack of print on the carton. The only way to distinguish the front from the back of the package would be the use of printed panels. The same is true for the right and left panels of the packages tested.

This supports the method of separating the orientations of the drops for the package analysis. Faces are separated into only four, not six, categories, which include bottom, top, front/back and left/right panels. The corners of the package are split into two divisions since the only difference between them are top corners and bottom corners. The difference between the BFR and BFL corners is insignificant for our purposes in this study, but the differences between the TFR and BFR corners are significant. Edges are divided between bottom edges, top edges and vertical edges for the same reasons.

Table D.1 shows the breakdown for the number of drops for each axis for the use of handholds in each package style. It is quite obvious when comparing the corner drops between the top and bottom corners; the results illustrate the bottom significantly outweighs the top in quantity of drops. Likewise, results are found with the bottom edges to all other edges; and the bottom face to all other faces. The combined bottom corners present a total of 284 freefalls and tosses compared to the combined top corners only showing 26 total drops. 370 bottom edges, 65 vertical edges and 32 top edges also illustrate the uneven results from the study. In addition, the faces show a similar imbalance of data with predominate bottom drops.

To better compare these results, the data is compiled into Table D.2. The data for each category is broken down into six separate sections of observation. In each section, a count of the total number of occurrences is input, then calculated against the percentage of the total number of drops. Also, see Figure C.5 for the corresponding charts.

The first section includes faces, edges and corners. This shows the edges of the smaller package size are dropped many times more than on the faces and corners; almost twice as much for each. However, on the larger package, the edge and corner drops occur almost exclusively with very few face drops. Comparing the data for the larger package size shows very little deviation concerning handholds. Hence the presence of handholds causes little difference in the orientations of the drops as it pertains to the general comparisons of faces, edges and corners.

The next three sections split the face, edge and corner data even further by observing the specific orientations of the individual sections. The smaller package had nearly twice as many face drops as the larger size for both the use and lack of handholds. Almost all face drops occurred on the bottom and vertical planes. As observed previously, there is little difference within each of the package styles when comparing handhold data.

The two orientations that start to demonstrate some differences between the package styles are the bottom edges and corners. The bottom edges for the smaller package size experience about 41% of all the drops when handholds are included, but only 33% when they are not present. The larger package size, however, shows approximately

38% bottom edge drops for both the use and lack of handholds. The results for the handholds shows the smaller package size consistently experiences many more occurrences for both the top edges and vertical edges than the larger carton. When the handholds are removed from the package design, more drops occur on vertical edges, as well as a few more top drops.

Similarly, the corner drops represent this consistency for the handholds. Bottom corners for both packages experience more percentage of drops when handholds are present, but when observing the actual numbers involved, the results are nearly identical. Comparing the two package sizes, the smaller package has about half as many bottom corner drops, but several more top corner drops. This shows the data may need careful consideration for the use of handholds in the package design when developing test parameters.

The predominance of the bottom drops stands out in the results. To illustrate this, another section is incorporated: the entire bottom versus the entire top versus all the vertical sides of the carton. The bottom includes all the bottom edges, corners and face drops; similarly, the top includes all the top portions of the package. The sides include only the vertical faces and vertical edges. The results of this section show the bottom had about 83% of all the drops for the smaller size with handholds present and only 70% without handholds. The larger size with handholds had 86% of all the drops and 80% without. The packages are dropped on the vertical sides half as many times with handholds (10%) than without (20%) for the smaller package, but much closer to equal results for the larger size (13 - 17%). This leaves about 6-10% and less than 4% for top drops on the smaller and larger package respectively.

The final section compares the front/back portions of the package to the left/right portions. These include the top and bottom edges of the carton on the respective sides as well as the flat face drops. The vertical edges and all corners are left out of this section because of the coincident axis to both the left/right and front/back planes. There is not much of a difference between the two package sizes by percentages. However, the amount of drops for the left/right portions for both designs is greater than the front/back only when handholds are present. These variables are nearly identical when the handholds are removed, proving the handholds have an effect on the orientation of drops. This may be due to the dropping of one handhold prior to the other causing the carton to land on the left or right bottom edge more often than on another axis.

All this information pertaining to drop orientation helps in the analysis of the drops in this study. However, without observing the orientations as they occur to each individual package size, the significance of this information may be vague. Figure C.6 is designed to illustrate the individual packages by the drop orientations for bottom corners, edges and faces; vertical edges and faces; and top corners, edges and faces. The smaller package size had a noticeable difference between the use and lack of handholds. More drops occur on the vertical edges, vertical faces and top portions of the carton when the handholds are removed. However, this is not evident on the larger package size. In fact, the larger size does not differ much for the orientations of drops when handholds are removed. These graphs also illustrate the smaller size had several more drops on the bottom face than the larger size. By observing these graphs, the smaller package may need different parameters in a test specification when contemplating the use of handholds, but the larger package size may be encompassed within one set of parameters. The two package sizes must also be separated when considering test parameters for each.

The other major variables evaluated for drop orientations are the routes and carriers for each of the package designs as seen on Table D.3. For each variable observed, the breakdown of the drops for each axis is relatively identical. The data shows little or no difference between the carriers used or the routes traveled. Hence, this further proves routes and carriers in this study do not affect the drop orientations during handling.

3.5. Drop Orientations by the Intensity of Drop Heights Data Analysis

The next step in the analysis is to compile the drop heights for each orientation and assess the severity of the drops for each orientation. The results from this correlate the drop orientations to the recommended drop heights used for laboratory testing. Some of the drop orientations are included in the charts in Figure C.7.

Each drop orientation is recorded within ranges of three inch increments for the tables used in the analysis. The data is separated to show how each group affects the results of the drop orientations as they correlate to the drop heights. Table D.4 shows the two package size drop heights for the basic orientations. The larger package size endures many more drops on the bottom edges and corners than the smaller size. It consistently shows lower quantities of drops at each of the lower drop heights than the smaller package size, but higher quantities of drops at the higher drop heights.

There is a significant difference for the bottom face drops. Where the larger package did not experience many of the flat bottom face drops, the smaller package had greater quantities and higher heights for this orientation of drops. Other obvious differences in drop quantities and heights for these particular orientations are further illustrated as percentages shown in the rest of the table. The smaller package had many more drops on the top and vertical sides of the packages. A major observation from the data in these tables is the size and weight of the larger package causes the drops to be more frequent for bottom of the box. This supports the 80-86% bottom drops for the larger package compared to only 70-83% for the smaller size found for the drop orientations earlier.

4.0. DEVELOPMENT OF A TEST SPECIFICATION

Utilizing the information collected throughout this study, a specification may be developed to correlate the actual dynamics captured by this study. There are many different methods in developing a test specification. Some tests, such as ASTM specify several drops on denoted axis and then one severe drop on the base of the package. Another method specifies the highest drop encountered and incorporates it into all the faces, some critical edges and corners. These types of test specifications are integrity evaluations on the protection levels of the package rather than a focused simulation of the actual distribution environment. Since the purpose of collecting the drop height data and all relevant information pertaining to this is to compose a test specification from the actual events within the distribution environment, all the features observed from the analysis of the data previously illustrated must be utilized.

The test method will include all data that has been analyzed thus far in the prior sections. Analysis for significance, drop heights, quantity of drops, drop orientations and severity of drop orientations will all be considered in composing the specification. Both an integrity test and a focused simulation test will be composed into the specification using the relevant information presented from this study. The integrity test specification will consist of two levels of assurance similar to ones used in the general-use standards developed by ASTM and ISTA. It will provide a single drop height level, quantity of drops and specify orientations for these drops. The focused simulation test specification will be developed similar to the integrity test specification, however it will include a range of drop heights to be used rather than a single height to simulate actual shipping It will also include the orientations specific to the data from this study rather that supporting all faces and some extraneous orientations

Prior to composing the specification, an assurance level of the tests must be agreed upon. The prior data in the drop height and quantity of drops sections are compiled with certain levels of cumulative frequencies set at 90%, 95%, and 99% specifically for this purpose. Comparing the assurance levels to ASTM standards for integrity testing, the 99% and 95% levels will be used as Assurance Level I and Assurance Level II respectively to simulate the two highest levels of confidence for the specification. These confidence levels will be used for all the characteristics of the test specification development. Other confidence limits are utilized in other portions of the specifications such as: 90% level for the medium level drops and 75% level for the lower drops. One drop will be used as the severe drop in the test; one-half of the total number of drops used in the test will experience the 90% level drops; and the remaining drops will be at the 75% level to represent the lower, less severe level of drops.[15]

4.1. Analysis of Variance for Significance of Data.

Utilizing the results provided by the ANOVA method, the significant difference and interactions between the package designs may be used to incorporate separate

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15 Young, 1996.

package laboratory parameters for the specification. Analysis of the data showed the handholds displayed an effect on the results of drop height and quantity of drops for the smaller package size, but not for the larger package. Hence, the test specifications will be composed utilizing the following categories for the individual differences in testing parameters:

- smaller package size with of handholds
- smaller package size without handholds
- larger package size with and without handholds

4.2. Drop Heights Data.

As illustrated previously, the drop heights for the packages must be compiled to show the heights at their respective assurance levels. The table that was shown in the earlier section of Data Analysis represents the data in the abridged form and will be used for the composition of the test specification (see Table 11).

Table 11. Drop Height Equivalents for Each Cumulative Frequency

Cumulative Percentage	**Smaller Package Size**		**Larger Package Size**
	Handholds	No Handholds	Handholds
75%	10 inches	10 inches	12 inches
90%	15 inches	16 inches	16 inches
95% (AL II)	16 inches	22 inches	19 inches
99% (AL I)	20 inches	34 inches	26 inches

4.3. Quantity of Drops Per Trip Data.

Similar to the results of the drop heights, the quantity of drops data that was provided in the earlier analysis is also shown (see Table 12). The data from the quantity of drops provides the test specification with the proper frequency of drops the package needs during testing in the laboratory to portray actual handling in the distribution environment.

Table 12. Quantity of Drops per Trip Equivalents for Each Cumulative Frequency

Cumulative Percentage	**Smaller Package Size**		**Larger Package Size**
	Handholds	No Handholds	Handholds and No Handholds
95%	10 drops	14 drops	9 drops
99%	11 drops	14 drops	10 drops

4.4. Drop Orientations Data.

This data requires close scrutiny to be used effectively in the test specification. As shown in Tables 13 and 14, each of the drop orientations must be correlated to a quantity of drops for each segment in the test. This is done by calculating the percentage of total drops for each orientation used in the test. For the smaller package size, both data with and without handholds for quantity of drops is used due to the different results from each. Since the data in the larger package size for the drop orientations is nearly identical for packages with and without handholds, the results for these packages will be combined.

Table 13. Smaller Package Size Number of Drops for Each Axis of Orientation
95% and 99% Assurance Levels (AL) Used

Axis of Orientation	Smaller Size with Handholds			Smaller Size w/ No Handholds		
	% of Total Drops	95% AL 16 inches	99% AL 20 inches	% of Total Drops	95% AL 22 inches	99% AL 34 inches
		10 drops	11 drops		14 drops	
bottom corner	26.36	2.63 drops	2.90 drops	17.09	2.39 drops	
bottom edge	41.09	4.11 drops	4.52 drops	33.05	4.63 drops	
bottom face	15.89	1.59 drops	1.75 drops	19.94	2.79 drops	
top corner	3.10	0.31 drops	0.34 drops	3.70	0.53 drops	
top edge	3.10	0.31 drops	0.34 drops	5.70	0.80 drops	
top face	0.00	0.00 drops	0.00 drops	0.28	0.04 drops	
vertical edge	3.49	0.35 drops	0.38 drops	9.69	1.36 drops	
vertical face	6.98	0.70 drops	0.77 drops	10.54	1.48 drops	

Table 14. Larger Package Size Number of Drops for Each Axis of Orientation
95% and 99% Assurance Levels (AL) Used

Axis of Orientation	Larger Package Size (with and without handholds)		
	% of Total Drops	95% AL 19 inches	99% AL 26 inches
		9 drops	10 drops
bottom corner	39.69	3.58 drops	3.97 drops
bottom edge	37.66	3.39 drops	3.76 drops
bottom face	5.09	0.46 drops	0.50 drops
top corner	1.27	0.11 drops	0.12 drops
top edge	1.02	0.09 drops	0.10 drops
top face	0.51	0.05 drops	0.05 drops
vertical edge	5.6	0.50 drops	0.56 drops
vertical face	9.16	0.82 drops	0.92 drops

The results of these calculations need to be rounded depending upon the total amount of drops for each orientation to be used for the test. When calculating the quantity of drops per orientation in a laboratory test, the highest potential for damage of the product and package system must be considered. Flat face drops usually produce the most amount of damage to the product, but the edges and corners disburse more damage to the packaging components within the package design. Tables 13 and 14 illustrate these calculations prior to any rounding.

4.5. Drop Height for Each Drop Orientation Data

Upon completing the tables for the suggested test specification, specific measures must be taken. The results previously illustrated support the use of the drop orientations needed during a laboratory test. For example, if a drop height of 30 inches was the only top drop throughout the study and all the bottom drops are less than 15 inches, consideration of incorporating this solitary high drop may be recommended. However, if this top drop is only one result of 2000 total drops (0.005% occurrence), the significance of its use in a laboratory test should be carefully considered since the possibilities of actually seeing this reflected in the environment is extremely low.

For the simulation test, the drop orientation with the highest drop height is first properly entered into the table under the maximum drop height. A flat drop usually produces much more severe damage to the product. However, if structural integrity of the package is possibly in question on another axis similar in height to that of the maximum drop experienced, the orientations may be interchanged for this purpose.

In the larger package size, for example, the highest drop orientation would be a bottom edge or bottom corner. As per the information on drop heights by orientation, a vertical edge would not be recommended. The highest drop on one of the vertical edges is only 23 inches, whereas a bottom edge had a drop of 36 inches and a bottom corner 32 inches. Therefore, the bottom edge and corner are the two orientations in contention for the highest drop height of the test specification. Most likely, the highest dropped orientation would be used, but there are only 5 drops over 18 inches for the bottom edges and 10 for the bottom corners. Even though the bottom edges experienced the highest drops, the bottom corners had a much higher frequency of these upper levels drops. Therefore, the bottom corner drop may be considered for the highest drop in the test, while the bottom edges and vertical edges may be used in the 90% AL range of drops.

4.6. Test Specification

Two types of specifications are derived from the results of this study: an integrity specification and a focused simulation specification. For both specifications, the smaller and larger package designs are segregated, as well as the handholds versus no handholds for the smaller package size. A separate set of parameters are developed for these three differences to better represent the handling specific to each.

The integrity test involves a thorough analysis of the package to ensure the protection provided by the package design will be satisfactory for the product. This style of testing usually proves to be the most rugged on the package design due to the testing of a single drop height level with wide disbursement of drops about the entire package. Even though some of the orientations of drops tested in an integrity test may not commonly occur in the environment, they do have a possibility of occurring in actual shipments.

Therefore, along with other orientations that may have a higher probability of occurrence, all the flat faces must be tested in an integrity test (see Table 15).

The other style of test is a focused simulation of the events that actually occur throughout a specified shipping environment. This test has many diverse drop height levels and frequencies of drops. Hence, this test is more representative of actual shipments through the distribution environment, which show the results in more "lifelike" terms for probability of occurrence (see Table 16).

Below are the abbreviations used for each of the orientations used in the test specifications.

BF - bottom face	BE - bottom edge	BC - bottom corner
TF - top face	TE - top edge	TC - top corner
VF - vertical face	VE - vertical edge	

Table 15. Suggested Integrity Test Using the Results from this Study

	Smaller Package Size		**Larger Package Size**
95% AL	With Handholds	No Handholds	
Drop Heights	16 inches	22 inches	19 inches
Quantity of Drops	10 drops	14 drops	9 drops
Drop Orientations	All 6 Faces plus 1 BF, 2 BE, 1 BC	All 6 Faces plus 1 BF, 3 BE, 2 BC, 1VF, 1VE	All 6 Faces plus 1 BF, 1 BE, 1 BC
	Smaller Package Size		**Larger Package Size**
99% AL	With Handholds	No Handholds	
Drop Heights	20 inches	34 inches	26 inches
Quantity of Drops	11 drops	14 drops	10 drops
Drop Orientations	All 6 Faces plus 1 BF, 2 BE, 2 BC	All 6 Faces plus 1 BF, 3 BE, 2 BC, 1VF, 1VE	All 6 Faces plus 1 BF, 2 BE, 1 BC

Table 16. Suggested Focused Simulation Test Using the Results from this Study.

Smaller Package Size with Handholds			
Assurance Level	Drop Heights	Qty of Drops	Drop Orientations
95% AL	10 inches	4 drops	BF, BE, BE, BC
	15 inches	5 drops	BF, VF, BE, BC, BC
	16 inches	1 drops	BE
99% AL	10 inches	5 drops	BF, BE, BE, VE, BC
	15 inches	5 drops	BF, VF, BE, BC, BC
	20 inches	1 drops	BE

Smaller Package Size with NO Handholds			
Assurance Level	Drop Heights	Qty of Drops	Drop Orientations
95% AL	10 inches	6 drops	BF. VF, BE, BE, TE. TC
	16 inches	7 drops	BF, VF, BE, BE, VE, BC, BC
	22 inches	1 drops	BF
99% AL	10 inches	6 drops	BF, VF, BE, BE, TE, TC
	16 inches	7 drops	BF, VF, BE, BE, VE, BC, BC
	34 inches	1 drops	BF

Larger Package Size with and without Handholds			
Assurance Level	Drop Heights	Qty of Drops	Drop Orientations
95% AL	12 inches	4 drops	BE, BE, VE, BC
	16 inches	4 drops	BF, VF. BE. BC
	19 inches	1 drops	BC
99% AL	12 inches	4 drops	BE, BE, VE, BC
	16 inches	5 drops	BF, VF, BE, BC, BC
	26 inches	1 drops	BC

CONCLUSIONS

Through the careful analysis of the data, many conclusions may be reached to further provide insight to the dynamics in the express carrier distribution environment. In addition, some of these results also present confusion. Drop heights, drop quantities, and orientations of the drops illustrate some extraordinary results throughout this study.

The size and weight of the package design have an overwhelming effect on the drop heights and the quantity of drops a package will experience. This is supported by the ANOVA method of statistical significance and the cumulative percentage tables for the distribution of the data. The smaller package size endures many more drops per trip than the larger size, but is handled better as illustrated by the lower drop heights. This contradicts most of the test specifications used by the packaging industry. It is assumed the larger, heavier packages would be dropped at lower, less severe heights.

The notion that handholds prevent rougher handling held true for the smaller package, but not for the larger package size. The smaller package is noticeably affected by the use of handholds incorporated in the design of the carton. Using them allowed for better protection of the product due to easier handling of the package, reducing drop heights and drop quantities through the distribution channels. To a degree, the use of handholds also supported more drops on the bottom portion of the carton because of the orientation specific method of manually handling for the package.

The larger package size, however, the use of handholds did not make a difference in the handling of the package. It was expected that this added feature should reflect a lower amount of drops and less severe drop heights due to a greater ease of handling. However, drop heights and quantities of drops remain nearly identical with and without handholds in the design. The ergonomics of this package may help to explain these results. The bulkiness and heavy weight of the package may require the sorter to handle the carton in an awkward fashion. This undesirable handling may lead to stress related problems for the sorter causing this phenomenon to occur.

Even though there is a slight difference in the drop heights encountered between the two carriers, both performed nearly identical handling hazards throughout the channels of distribution. This difference may be related to the time allotted for the transportation and handling of the products. Carrier A needed to provide satisfactory receipt of the product within one working day, whereas Carrier G is allowed two to three working days for delivery. This data supports the results found in other studies that proved the carriers and routes are insignificant factors in the distribution environment when determining the necessary package requirements.

The drop orientations between packages was significantly different. Nearly 80% of all the drops for the manual handling within the sort processes occur on the bottom portion of the box. This signifies a very low likelihood that drops will occur on another axis. Even though the highest percentage of drops may happen on the bottom portion of the box, some high drops may occur on another axis. These other axis must not be neglected in the severity of the dynamics and need to be tested to drop height levels comparable to the bottom portion of the carton. However, not as many repetitive drops are necessary due to the percentage of occurrences for each axis.

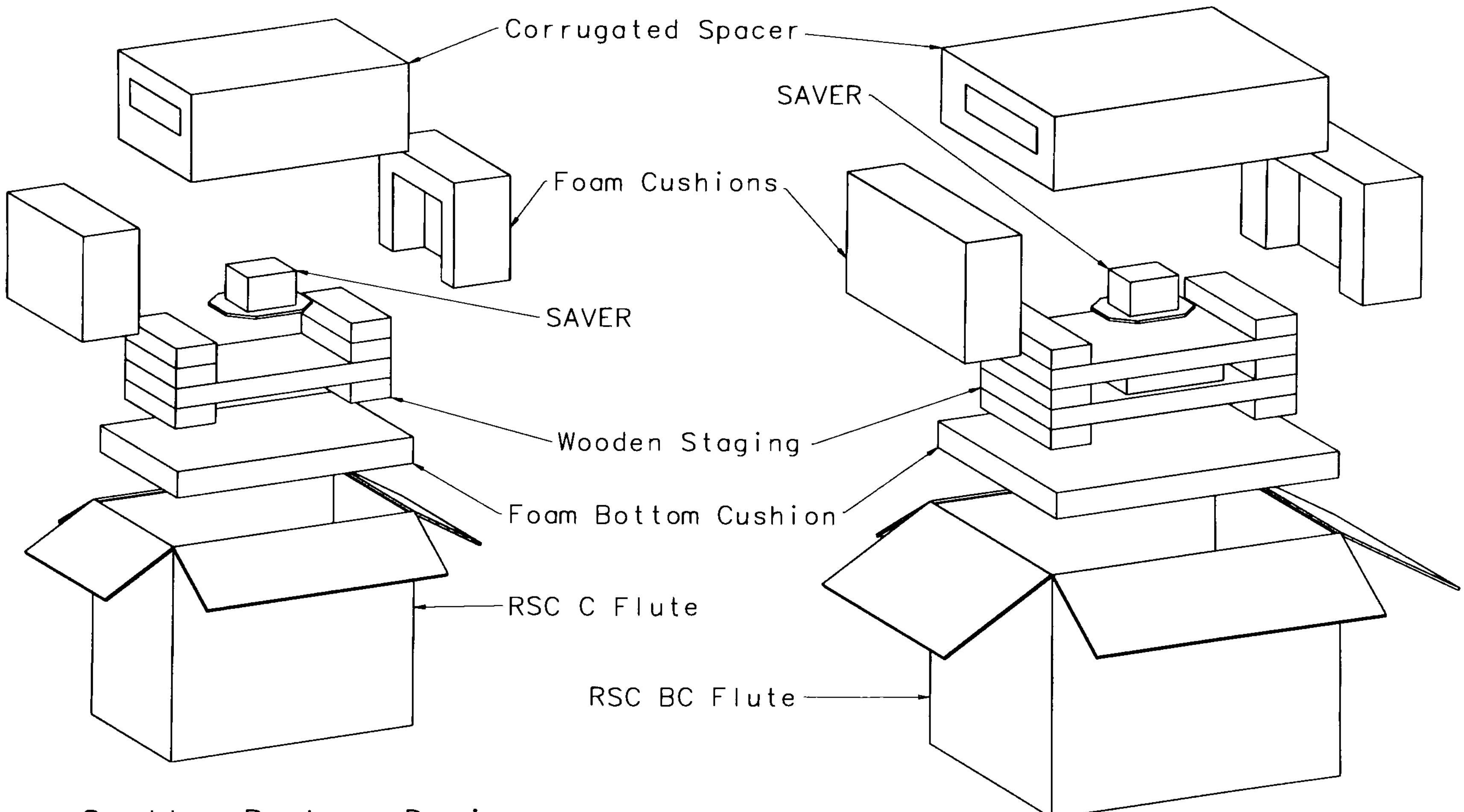
Since the bottom experienced a larger quantity of drops, this must be incorporated into laboratory testing. Repetitive drops to several axis should be used in conjunction with current testing procedures or a new specification must be developed to ensure the dynamics of the actual environment are fully simulated. Without the protection of repetitive drops for certain axis, packages may be subject to damage. This may attribute to some of the damage in today's packages that do not account for this type of testing. The integrity test developed from the results of this study was designed as an alternate test procedure to help improve on the current test parameters used in current laboratory specifications. This test provides added drops to critical axis as well as supporting repetitive drops to axis with a much higher probability of occurrence.

The focused simulation specification may be used as a design assessment tool of actual manual handling recorded from the environment. However, this specification, since it is only a simulation of the handling, must be accompanied by a package performance test that incorporates all the possibilities of the dynamics that may occur within the shipping environment to ensure the integrity of the protection provided. For example, even though the top of the packages are not subjected to high or frequent drops, it should not be overlooked in the package design since all dynamics are random in nature. A lack of protection for these axis will surely, in the long run, prove hazardous to the product since all packages are not handled identically. The focused simulation specification is a good risk assessment tool that could provide an effective argument to the protection of packages, but may not be used solely as an instrument to prove adequacies in the package design.

This data provides a better understanding of the distribution environment for the small parcel express carriers. With careful thought and improved insight, designs may be modified to eliminate excess material, reduce costs in shipping, and provide better protection. As more testing is performed and data analyzed, a better understanding of the levels of hazards contributed from manual handling in the distribution environment will be realized. The packaging of products could only benefit from the extra confidence levels of assurance in performance testing.

Appendix A

Figure A.1. Assembly Drawings for the Package Designs



Smaller Package Design
19.5" x 12.5" x 15.75"   14 lbs.

Larger Package Design
23.25" x 19.25" x 18"   52 lbs.

Figure A.2. Reference Table of Analysis of Variance (ANOVA)[16]

ANOVA - One-Tailed Test; Unequal Sample Sizes						
Groups	Count	Sum	Average	Variance		
Group x	Count (x)	Σx_i	$\mu(x)$	$\sigma(x)$		
Group y	Count (y)	Σy_i	$\mu(y)$	$\sigma(y)$		
Totals	N†				alpha = 0.05	
Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Computed F-Dist.	P-Value	Critical F-Dist.
Treatments	(a)	k-1*	(d)	(f)	(g)	(h)
Error	(b)	N-k*	(e)			
Totals	(c)	N-1	Conclusions: Significance (YES/NO)			

* k = number of groups †N = total count of events analyzed

Description of the above calculations:

(a) Sum of Squares for the Treatment Aggregates:

$$SSA = \sum_{i=1}^{k} \frac{T_{i.}^2}{n_i} - \frac{T_{..}^2}{N}$$

(b) Sum of Squares for the Error Aggregates:

$$SSE = SST - SSA$$

(c) Sum of Squares for the Total Aggregates:

$$SST = \sum_{i=1}^{k} \sum_{j=1}^{n_i} y_{ij}^2 - \frac{T_{..}^2}{N}$$

The Mean Squares:

(d)
$$s_1^2 = \frac{SSA}{k-1}$$

(e)
$$s^2 = \frac{SSE}{N-k}$$

(f) The computed F-Distribution:

$$f = \frac{s_1^2}{s^2}$$

(g) The P-Value: Using statistical analysis tables, the result of the P-Value may be found and compared to the implemented alpha value.

(h) The Critical F-Distribution: $F_\alpha(k-1, N-k)$; where F is an F-Distribution of two different degrees of freedom calculated to the confidence level of α.

16 Walpole, pp. 471-2.

Appendix B

B.1 Drop Height Significance (All Data)

B.2 Drop Height Significance for Package Size

B.3 Drop Height Significance for Use of Handholds

B.4 Interaction of Variables for Statistical Significance of Drop Height

B.5 Quantity of Drops Significance (All Data)

B.6 Quantity of Drops Significance for Package Size

B.7 Quantity of Drops Significance for Use of Handholds

B.8 Interaction of Variables for Statistical Significance of Quantity of Drops

B.1. Drop Height Significance

COMPARISON OF THE TWO DIFFERENT PACKAGE DESIGNS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Smaller Size	609	6449.12	9.121810	28.348741		
Larger Size	393	3895.08	9.911145	26.776769		
TOTAL	1002				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	109.97572624	1	109.97572624	15.50552898	0.00008797	3.85077449
WITHIN	7092.67812546	1000	7.09267813			
TOTAL	7202.65385170	1001	Conclusion: YES, Significant Difference			

COMPARISON OF THE TWO DIFFERENT CARRIERS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Carrier A	484	4726.50	9.765496	31.814799		
Carrier G	518	4574.23	8.830560	23.356623		
TOTAL	1002				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	218.71128186	1	218.71128186	7.96996960	0.00485034	3.85077449
WITHIN	27441.92171864	1000	27.44192172			
TOTAL	27660.63300050	1001	Conclusion: YES, Significant Difference			

COMPARISON OF THE TWO DIFFERENT ROUTES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Colorado	512	4777.37	9.330801	29.976131		
Minnesota	490	4523.36	9.231347	25.235896		
TOTAL	1002				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	2.47651780	1	2.47651780	0.08954023	0.76482465	3.85077449
WITHIN	27658.15648270	1000	27.65815648			
TOTAL	27660.63300050	1001	Conclusion: No Significance			

COMPARISON OF THE USE OF HANDHOLDS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Handholds	451	4053.95	8.988803	21.652683		
NO Handholds	551	5248.78	9.522287	32.447894		
TOTAL	1002				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	70.58352837	1	70.58352837	2.55829655	0.11003262	3.85077449
WITHIN	27590.04947213	1000	27.59004947			
TOTAL	27660.63300050	1001	Conclusion: No Significance			

B.2. Drop Height Significance for Package Size

Smaller Package Size

COMPARISON OF THE USE OF HANDHOLDS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Handholds	258	2162.70	8.382558	18.440133		
NO Handholds	351	3242.95	9.239174	34.457435		
TOTAL	609				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	109.11426673	1	109.11426673	3.94258628	0.04752784	3.85682370
WITHIN	16799.21637203	607	27.67580951			
TOTAL	16908.33063875	608	Conclusion:	YES, Significant Difference		

COMPARISON OF THE TWO DIFFERENT CARRIERS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Carrier A	292	2744.62	9.399384	33.370167		
Carrier G	317	2661.03	8.394416	22.291472		
TOTAL	609				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	153.50713268	1	153.50713268	5.56131370	0.01867776	3.85682370
WITHIN	16754.82350608	607	27.60267464			
TOTAL	16908.33063875	608	Conclusion:	YES, Significant Difference		

COMPARISON OF THE TWO DIFFERENT ROUTES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Colorado	306	2744.85	8.970098	30.299221		
Minnesota	303	2660.80	8.781518	25.369716		
TOTAL	609				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	5.41424004	1	5.41424004	0.19443057	0.65941140	3.85682370
WITHIN	16902.91639871	607	27.84664975			
TOTAL	18908.33063875	608	Conclusion:	No Significance		

Larger Package Size

COMPARISON OF THE USE OF HANDHOLDS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Handholds	193	1891.25	9.799223	24.911518		
NO Handholds	200	2003.83	10.019150	28.687092		
TOTAL	393				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	4.75064581	1	4.75064581	0.17704423	0.67415695	3.86535105
WITHIN	10491.74273892	391	26.83310163			
TOTAL	10496.49338473	392	Conclusion:	No Significance		

COMPARISON OF THE TWO DIFFERENT CARRIERS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Carrier A	192	1981.88	10.322292	29.095110		
Carrier G	201	1913.20	9.518408	24.379343		
TOTAL	393				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	63.45870252	1	63.45870252	2.37824885	0.12384430	3.86535105
WITHIN	10433.03468221	391	26.68295315			
TOTAL	10496.49338473	392	Conclusion:	No Significance		

COMPARISON OF THE TWO DIFFERENT ROUTES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Colorado	206	2032.52	9.866602	29.158972		
Minnesota	187	1862.56	9.960214	24.290566		
TOTAL	393				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	0.85897193	1	0.85897193	0.03199978	0.85812079	3.86535105
WITHIN	10495.63441280	391	26.84305476			
TOTAL	10496.49338473	392	Conclusion:	No Significance		

B.3. Drop Height Significance for Use of Handholds

Using Handholds

COMPARISON OF THE TWO DIFFERENT PACKAGES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Smaller Size	258	2162.70	8.382558	18.440133		
Larger Size	193	1891.25	9.799223	24.911518		
TOTAL	451				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	221.58205839	1	221.58205839	10.44833365	0.00131800	3.88225232
WITHIN	9522.12549505	449	21.20740645			
TOTAL	9743.70755344	450	Conclusion:	YES, Significant Difference		

COMPARISON OF THE TWO DIFFERENT CARRIERS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Carrier A	212	1962.32	9.256226	24.327614		
Carrier G	239	2091.63	8.751590	19.251980		
TOTAL	451				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	28.60977649	1	28.60977649	1.32225017	0.25080071	3.86225232
WITHIN	9715.09777695	449	21.63718881			
TOTAL	9743.70755344	450	Conclusion:	No Significance		

COMPARISON OF THE TWO DIFFERENT ROUTES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Colorado	231	2129.31	9.217792	23.118052		
Minnesota	220	1924.64	8.748364	20.099198		
TOTAL	451				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	24.83116850	1	24.83116850	1.14716910	0.28471792	3.86225232
WITHIN	9718.87638494	449	21.64560442			
TOTAL	9743.70755344	450	Conclusion:	No Significance		

NO Handholds

COMPARISON OF THE TWO DIFFERENT PACKAGES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Smaller Size	351	3242.95	9.239174	34.457435		
Larger Size	200	2003.83	10.019150	28.687092		
TOTAL	551				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	77.50830279	1	77.50830279	2.39475810	0.12231881	3.85845231
WITHIN	17768.83361590	549	32.36581715			
TOTAL	17848.34191869	550	Conclusion:	No Significance		

COMPARISON OF THE TWO DIFFERENT CARRIERS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Carrier A	272	2764.18	10.162426	37.400676		
Carrier G	279	2482.60	8.898208	26.944732		
TOTAL	551				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	220.12321622	1	220.12321622	6.85612994	0.00907770	3.85845231
WITHIN	17626.21870247	549	32.10604500			
TOTAL	17846.34191869	550	Conclusion:	YES, Significant Difference		

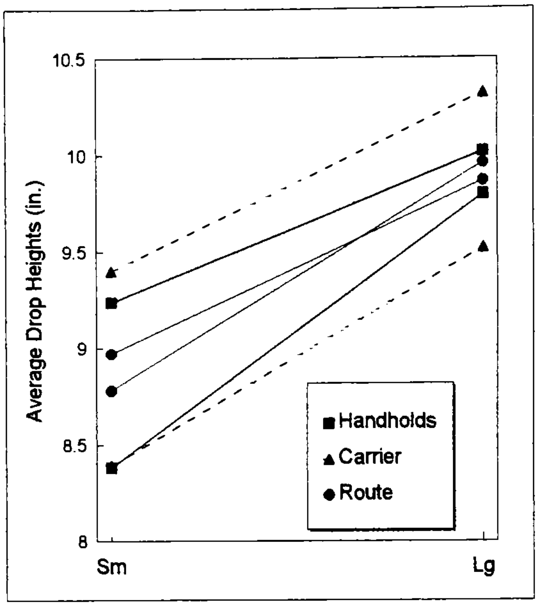
COMPARISON OF THE TWO DIFFERENT ROUTES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Colorado	281	2648.06	9.423701	35.697414		
Minnesota	270	2598.72	9.624889	29.165400		
TOTAL	551				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	5.57342114	1	5.57342114	0.17150652	0.67893811	3.85845231
WITHIN	17840.76849756	549	32.49684608			
TOTAL	17846.34191869	550	Conclusion:	No Significance		

B.4. Interaction of Variables for Statistical Significance of Drop Heights

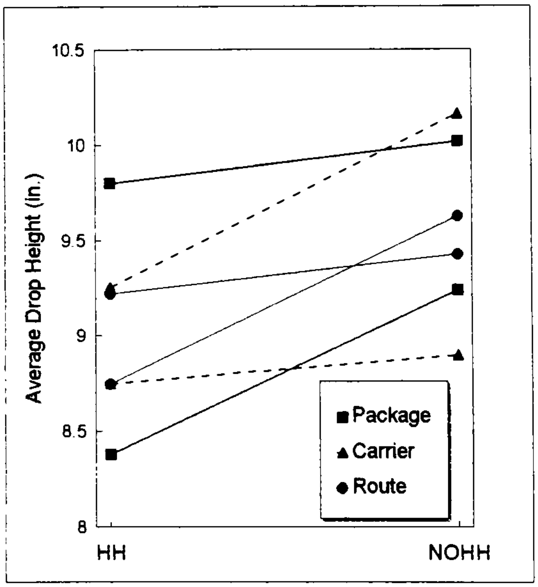
Average Drop Heights Recorded

	Package Size Sm	Lg
Handholds		
HH	8.382558	9.799223
NOHH	9.239174	10.019150
Carrier		
A	9.399384	10.322292
G	8.394416	9.518408
Route		
CO	8.970098	9.866602
MN	8.781518	9.960214



Average Drop Heights Recorded

	Use of Handholds HH	NOHH
Package Size		
Sm	8.382558	9.239174
Lg	9.799223	10.019150
Carrier		
A	9.256226	10.162426
G	8.751590	6.898206
Route		
CO	9.217792	9.423701
MN	8.748364	9.624889



B.5. Quantity of Drops Significance

COMPARISON OF THE TWO DIFFERENT PACKAGE SIZES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Smaller Size	80	609.00	7.612500	7.227690		
Larger Size	78	393.00	5.038462	4.323177		
TOTAL	158				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	261.67218841	1	261.67218841	45.16220901	0.00000000	3.90176060
WITHIN	903.87211538	156	5.79405202			
TOTAL	1165.54430380	157	Conclusion: YES, Significant Difference			

COMPARISON OF THE TWO DIFFERENT CARRIERS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Carrier A	79	482.00	6.101266	6.681921		
Carrier G	79	520.00	6.582278	8.143784		
TOTAL	158				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	9.13924051	1	9.13924051	1.23289111	0.26855408	3.90176060
WITHIN	1156.40506329	156	7.41285297			
TOTAL	1165.54430380	157	Conclusion: No Significance			

COMPARISON OF THE TWO DIFFERENT ROUTES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Colorado	80	512.00	6.400000	7.154430		
Minnesota	78	490.00	6.282051	7.789544		
TOTAL	158				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	0.54943200	1	0.54943200	0.07357233	0.78656334	3.90176060
WITHIN	1164.99487179	156	7.46791584			
TOTAL	1165.54430380	157	Conclusion: No Significance			

COMPARISON OF THE USE OF HANDHOLDS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Handholds	78	451.00	5.782051	5.263570		
NO Handholds	80	551.00	6.887500	9.012500		
TOTAL	158				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	48.26193200	1	48.26193200	6.73854845	0.01033609	3.90176060
WITHIN	1117.28237179	156	7.16206649			
TOTAL	1165.54430380	157	Conclusion: YES, Significant Difference			

B.6. Quantity of Drops Significance for Package Size

Smaller Package Size

COMPARISON OF THE USE OF HANDHOLDS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Handholds	40	258.00	6.450000	5.023077		
NO Handholds	40	351.00	8.775000	6.845513		
TOTAL	80				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	108.11250000	1	108.11250000	18.21825547	0.00005492	3.96347192
WITHIN	462.87500000	78	5.93429487			
TOTAL	570.98750000	79	Conclusion: YES, Significant Difference			

COMPARISON OF THE TWO DIFFERENT CARRIERS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Carrier A	40	290.00	7.250000	6.038462		
Carrier G	40	319.00	7.975000	8.332692		
TOTAL	80				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	10.51250000	1	10.51250000	1.48300013	0.23010665	3.96347192
WITHIN	560.47500000	78	7.18557692			
TOTAL	570.98750000	79	Conclusion: No Significance			

COMPARISON OF THE TWO DIFFERENT ROUTES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Colorado	40	306.00	7.650000	6.592308		
Minnesota	40	303.00	7.575000	8.045513		
TOTAL	80				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	0.11250000	1	0.11250000	0.01537114	0.90164973	3.96347192
WITHIN	570.87500000	78	7.31891026			
TOTAL	570.98750000	79	Conclusion: No Significance			

Larger Package Size

COMPARISON OF THE USE OF HANDHOLDS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Handholds	38	193.00	5.078947	4.669275		
NO Handholds	40	200.00	5.000000	4.102564		
TOTAL	78				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	0.12145749	1	0.12145749	0.02773976	0.86816444	3.96675966
WITHIN	332.76315789	76	4.37846260			
TOTAL	332.88461538	77	Conclusion: No Significance			

COMPARISON OF THE TWO DIFFERENT CARRIERS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Carrier A	39	192.00	4.923077	4.704453		
Carrier G	39	201.00	5.153846	4.028340		
TOTAL	78				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	1.03846154	1	1.03846154	0.23783032	0.62718147	3.96675966
WITHIN	331.84615385	76	4.36639676			
TOTAL	332.88461538	77	Conclusion: No Significance			

COMPARISON OF THE TWO DIFFERENT ROUTES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Colorado	40	206.00	5.150000	4.694872		
Minnesota	38	187.00	4.921053	4.020626		
TOTAL	78				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	1.02145749	1	1.02145749	0.23392404	0.63002000	3.96675966
WITHIN	331.86315789	76	4.36662050			
TOTAL	332.88461538	77	Conclusion: No Significance			

B.7. Quantity of Drops Significance for Use of Handholds

Using Handholds

COMPARISON OF THE TWO DIFFERENT PACKAGES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Smaller Size	40	258.00	6.450000	5.023077		
Larger Size	38	193.00	5.078947	4.669275		
TOTAL	78				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	36.63171390	1	36.63171390	7.55163676	0.00748487	3.96675966
WITHIN	368.66315789	76	4.85083102			
TOTAL	405.29487179	77	Conclusion: YES, Significant Difference			

COMPARISON OF THE TWO DIFFERENT CARRIERS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Carrier A	39	212.00	5.435897	4.568151		
Carrier G	39	239.00	6.128205	5.851552		
TOTAL	78				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	9.34615385	1	9.34615385	1.79393861	0.18443881	3.96675966
WITHIN	395.94871795	76	5.20985155			
TOTAL	405.29487179	77	Conclusion: No Significance			

COMPARISON OF THE TWO DIFFERENT ROUTES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Colorado	40	231.00	5.775000	5.460897		
Minnesota	38	220.00	5.789474	5.197724		
TOTAL	78				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	0.00408232	1	0.00408232	0.00076552	0.97799951	3.96675966
WITHIN	405.29078947	76	5.33277355			
TOTAL	405.29487179	77	Conclusion: No Significance			

NO Handholds

COMPARISON OF THE TWO DIFFERENT PACKAGES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Smaller Size	40	351.00	8.775000	6.845513		
Larger Size	40	200.00	5.000000	4.102564		
TOTAL	80				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	285.01250000	1	285.01250000	52.06622168	0.00000000	3.96347192
WITHIN	426.97500000	78	5.47403848			
TOTAL	711.98750000	79	Conclusion: YES, Significant Difference			

COMPARISON OF THE TWO DIFFERENT CARRIERS

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Carrier A	40	270.00	6.750000	8.038462		
Carrier G	40	281.00	7.025000	10.178846		
TOTAL	80				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	1.51250000	1	1.51250000	0.16605088	0.68476187	3.96347192
WITHIN	710.47500000	78	9.10865385			
TOTAL	711.98750000	79	Conclusion: No Significance			

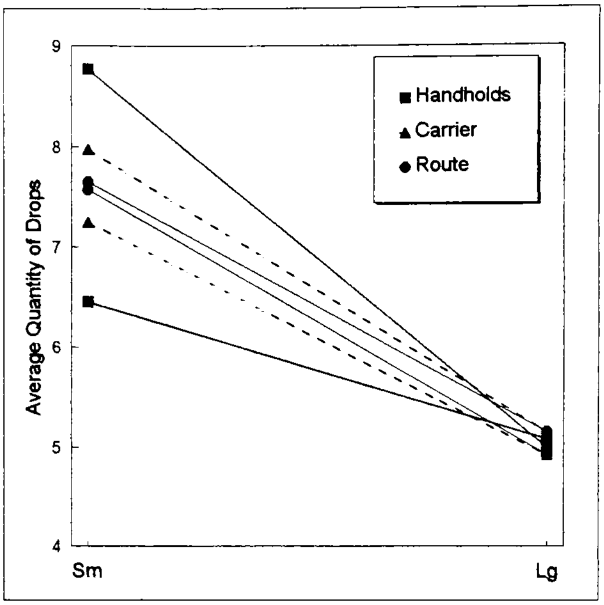
COMPARISON OF THE TWO DIFFERENT ROUTES

GROUPS	COUNT	SUM	AVERAGE	VARIANCE		
Colorado	40	281.00	7.025000	8.230128		
Minnesota	40	270.00	6.750000	9.987179		
TOTAL	80				alpha =	0.05
SOURCE	SS	df	MS	F	P-value	F crit
BETWEEN	1.51250000	1	1.51250000	0.16605088	0.68476187	3.96347192
WITHIN	710.47500000	78	9.10865385			
TOTAL	711.98750000	79	Conclusion: No Significance			

B.8. Interaction of Variables for Statistical Significance of Quantity of Drops

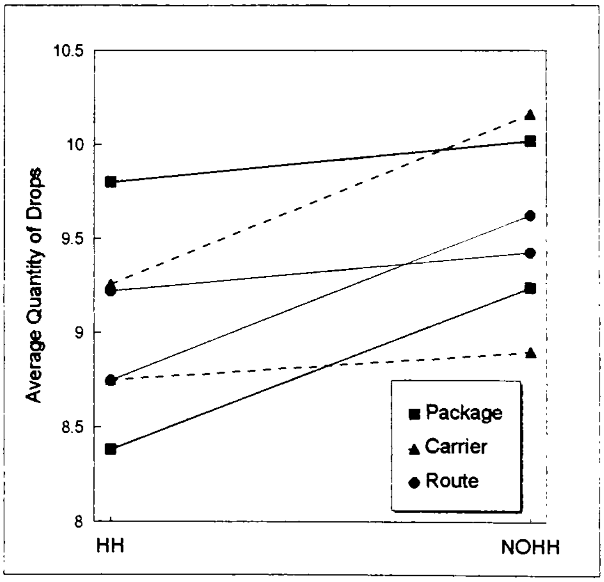
Average Quantity of Drops Recorded

	Package Size Sm	Package Size Lg
Handholds		
HH	6.450000	5.078947
NOHH	8.775000	5.000000
Carrier		
A	7.250000	4.923077
G	7.975000	5.153846
Route		
CO	7.650000	5.150000
MN	7.575000	4.921053



Average Quantity of Drops Recorded

	Use of Handholds HH	Use of Handholds NOHH
Package Size		
Sm	8.382558	9.239174
Lg	9.799223	10.019150
Carrier		
A	9.256226	10.162426
G	8.751590	8.898206
Route		
CO	9.217792	9.423701
MN	8.748364	9.624889



Appendix C

Figure C.1. Drop Height Distribution

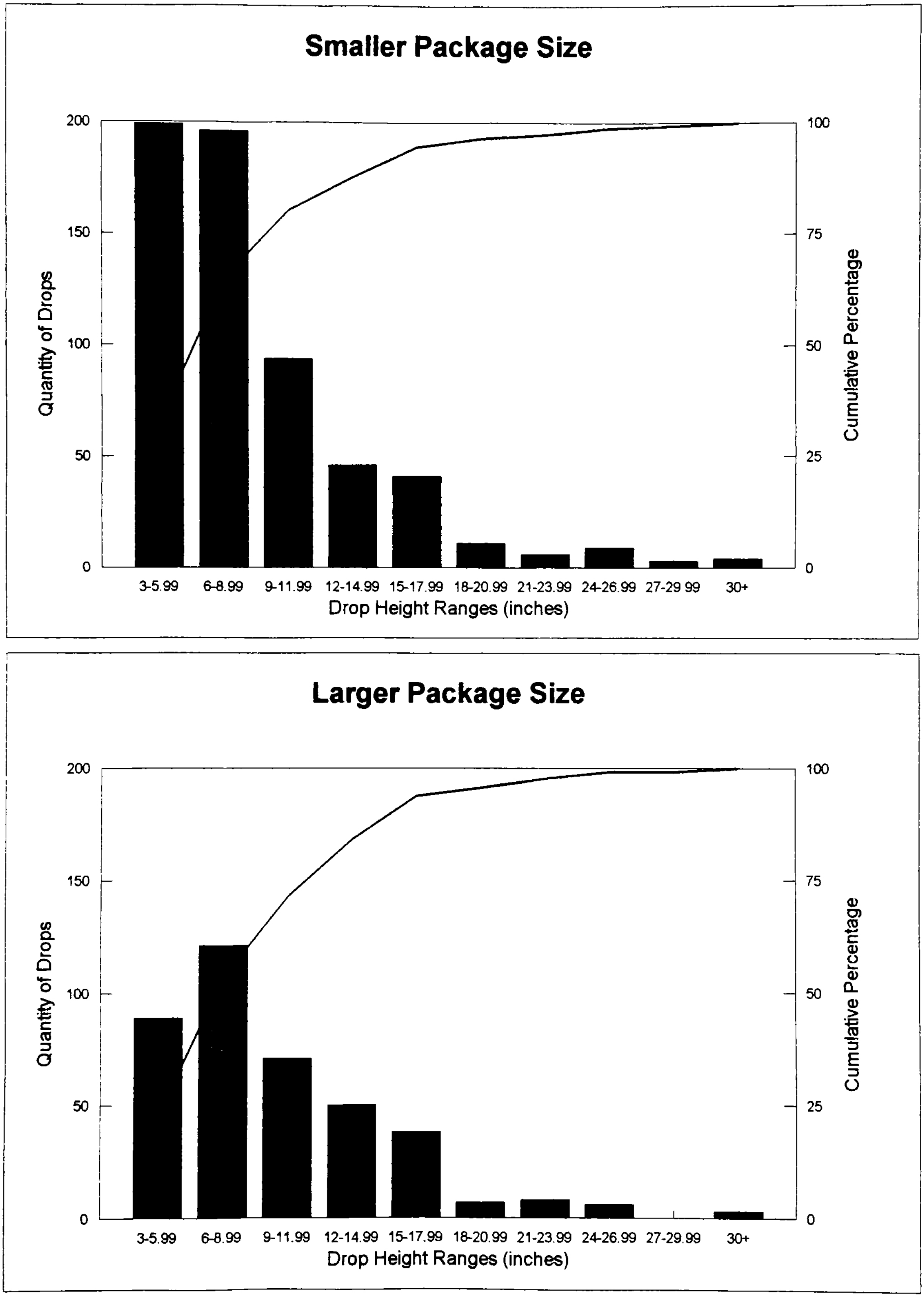
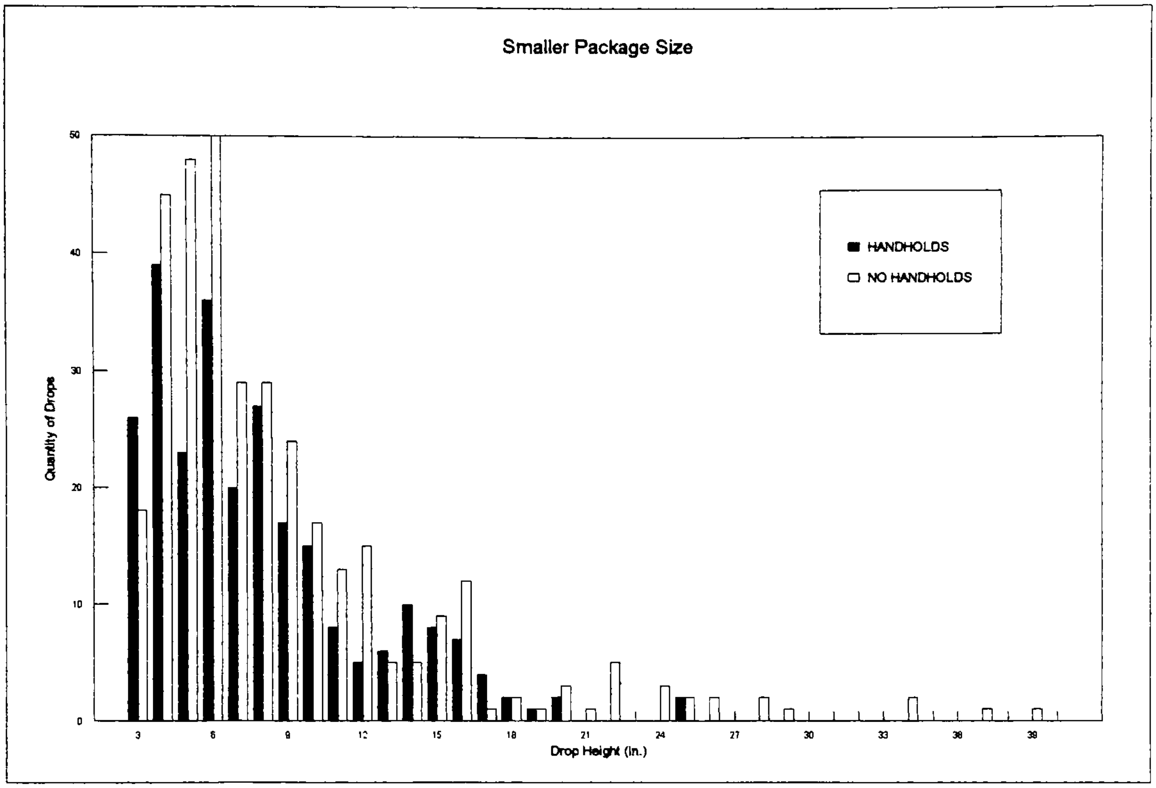


Figure C.2 Drop Height Distribution



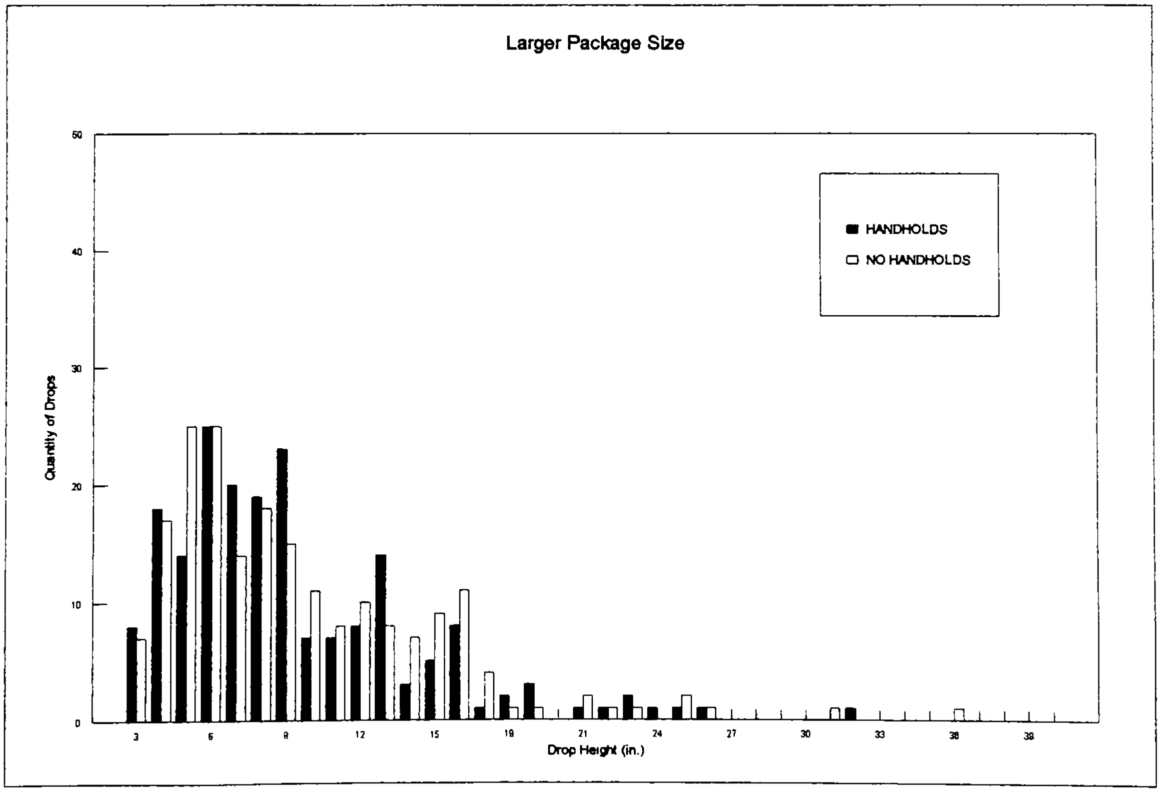
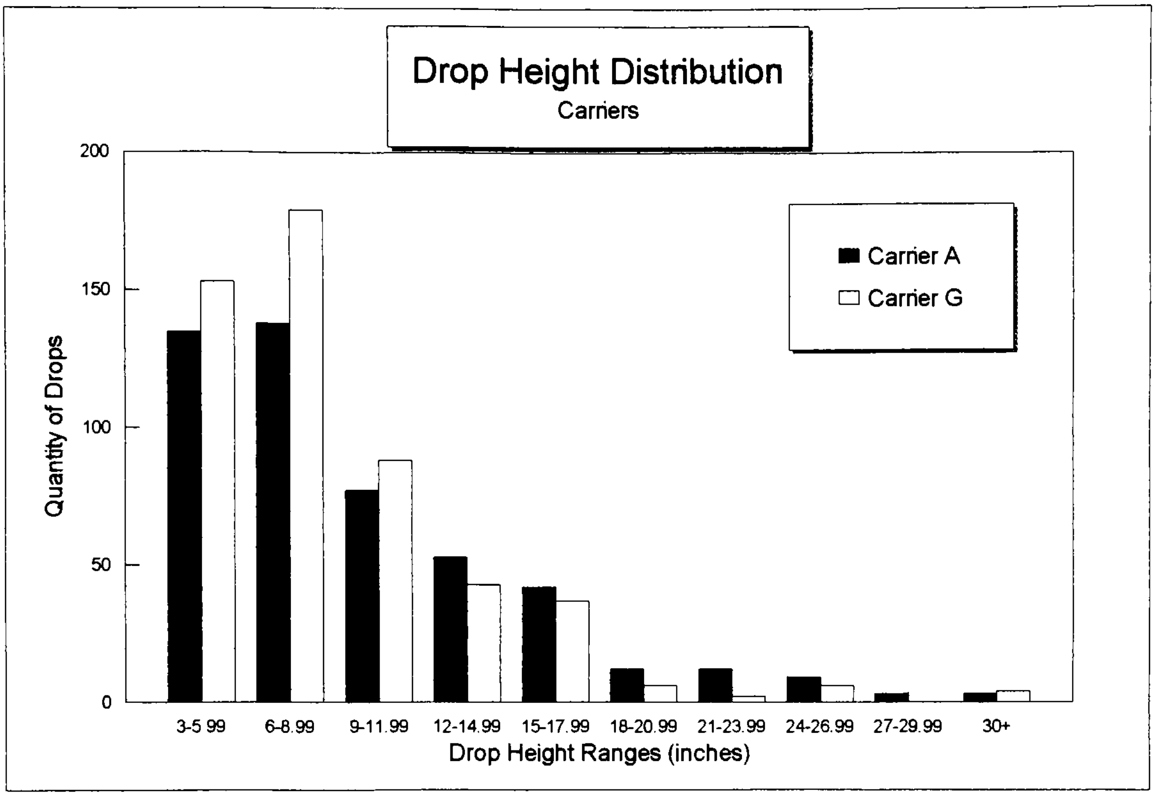


Figure C.3. Drop Height Distribution



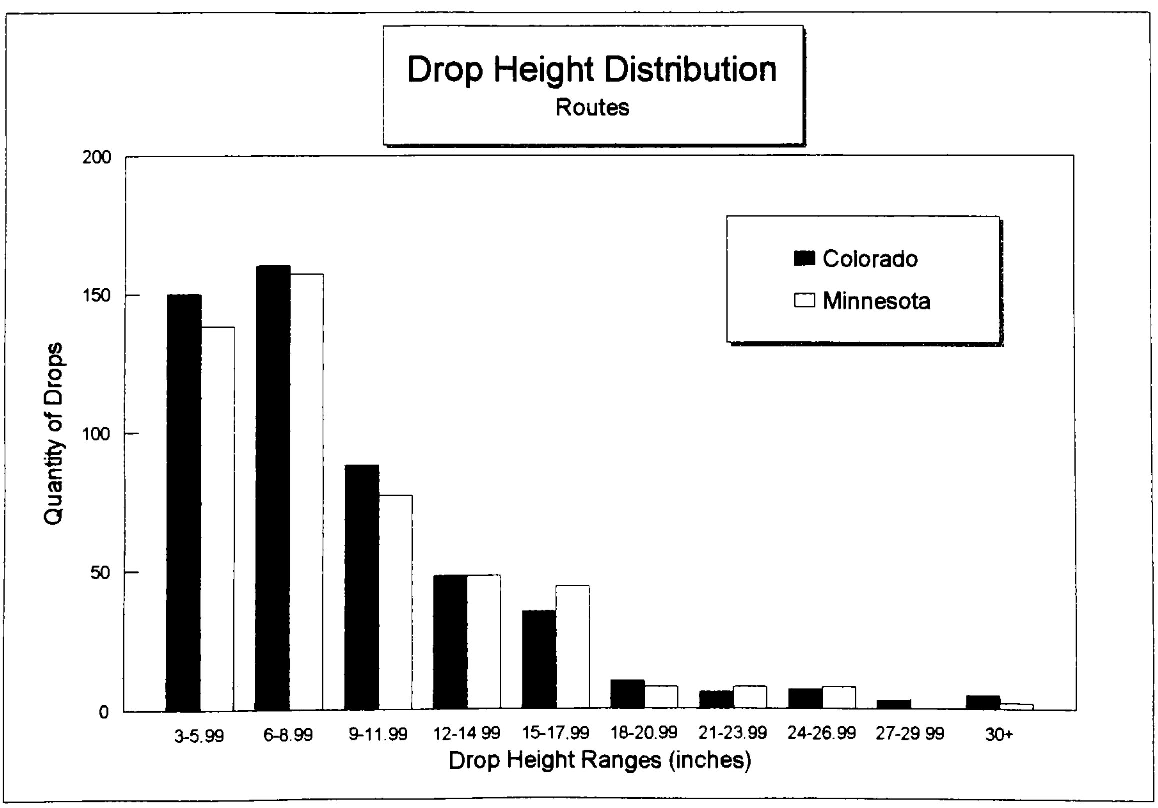
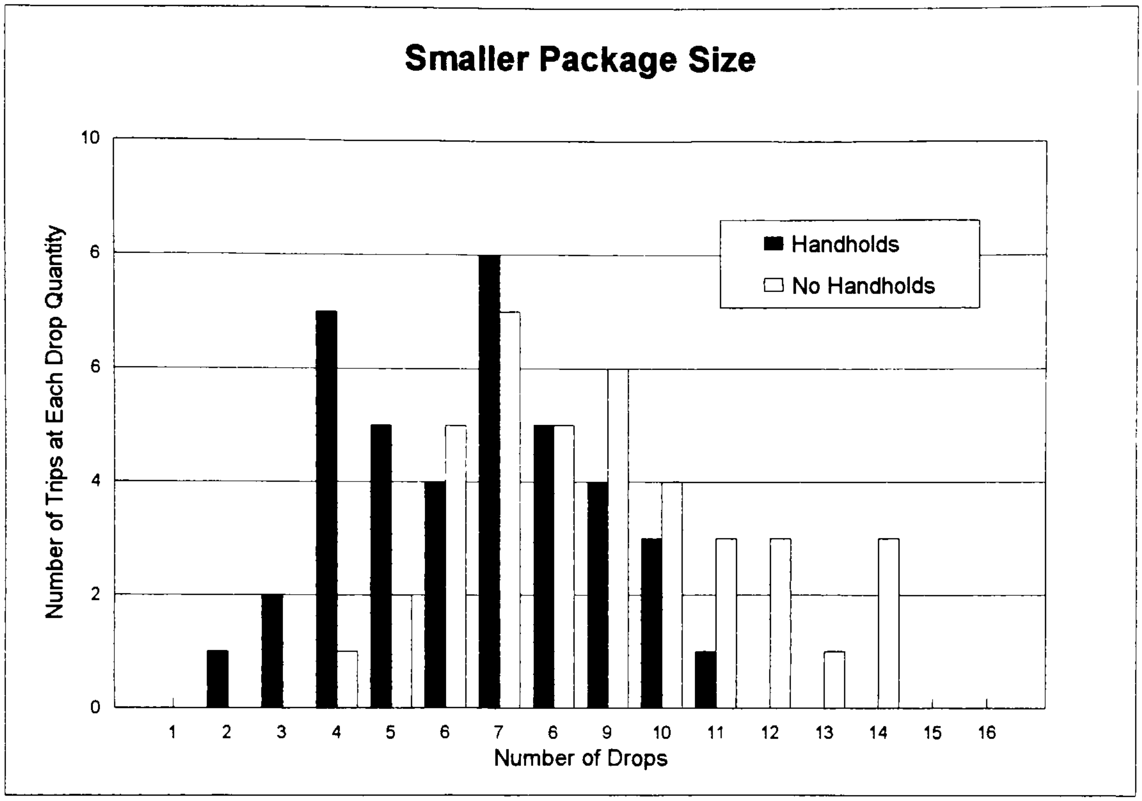


Figure C.4 Quantity of Drops Distribution



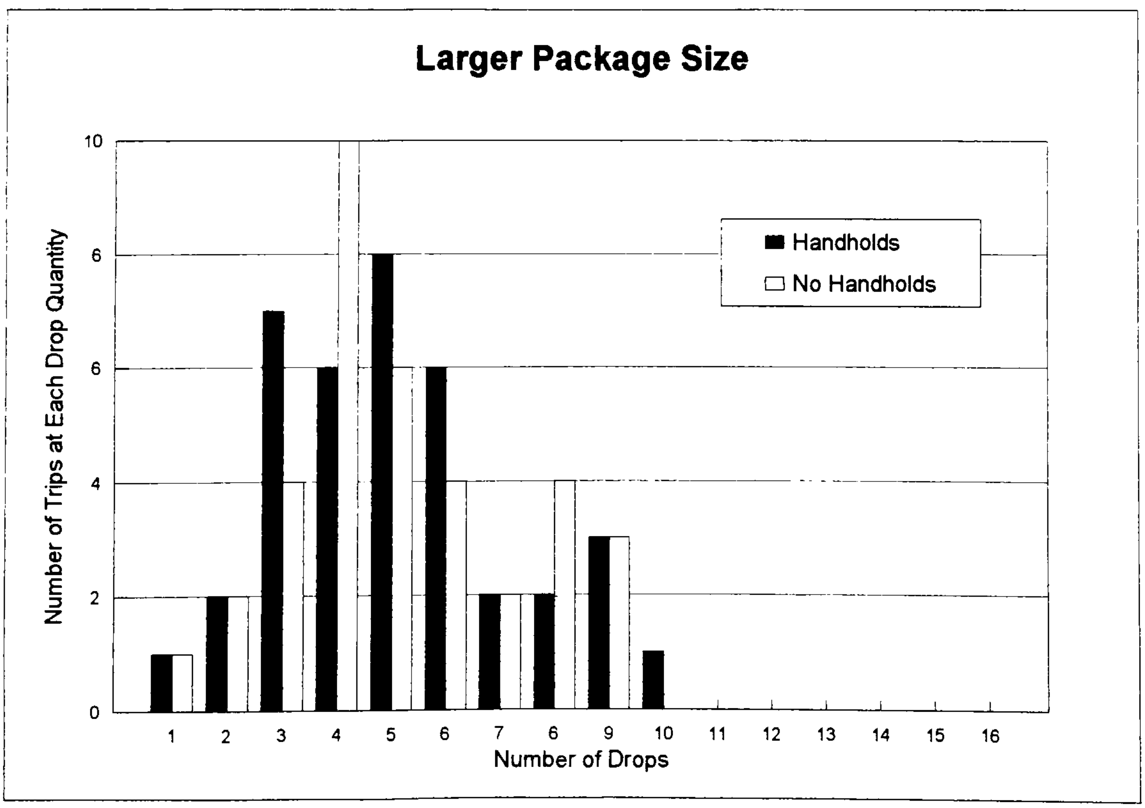


Figure C.5. Drop Orientation Distribution Charts (1 of 4)

Smaller Package Size

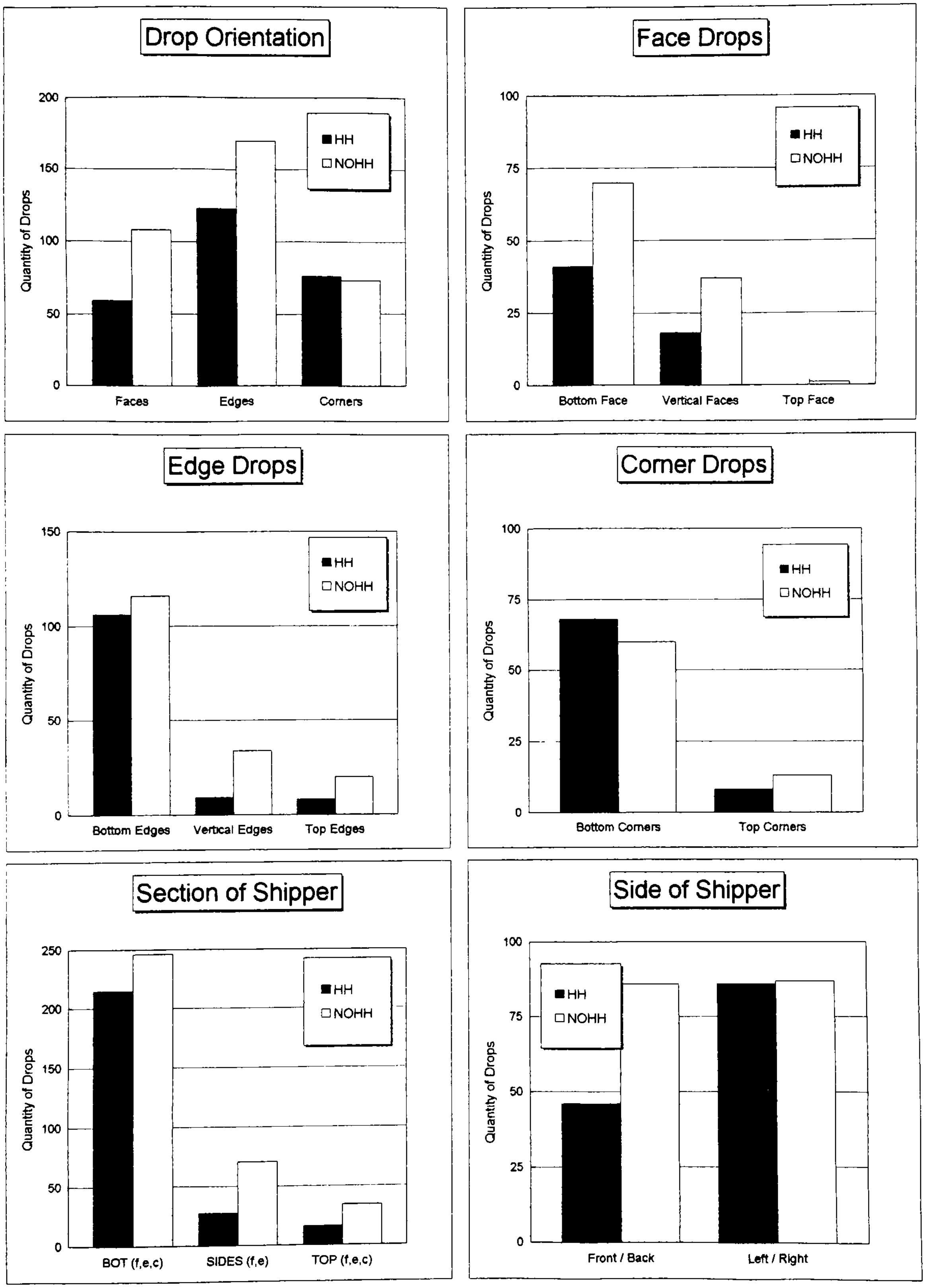


Figure C.5. (con't) Drop Orientation Distribution Charts (2 of 4)
Larger Package Size

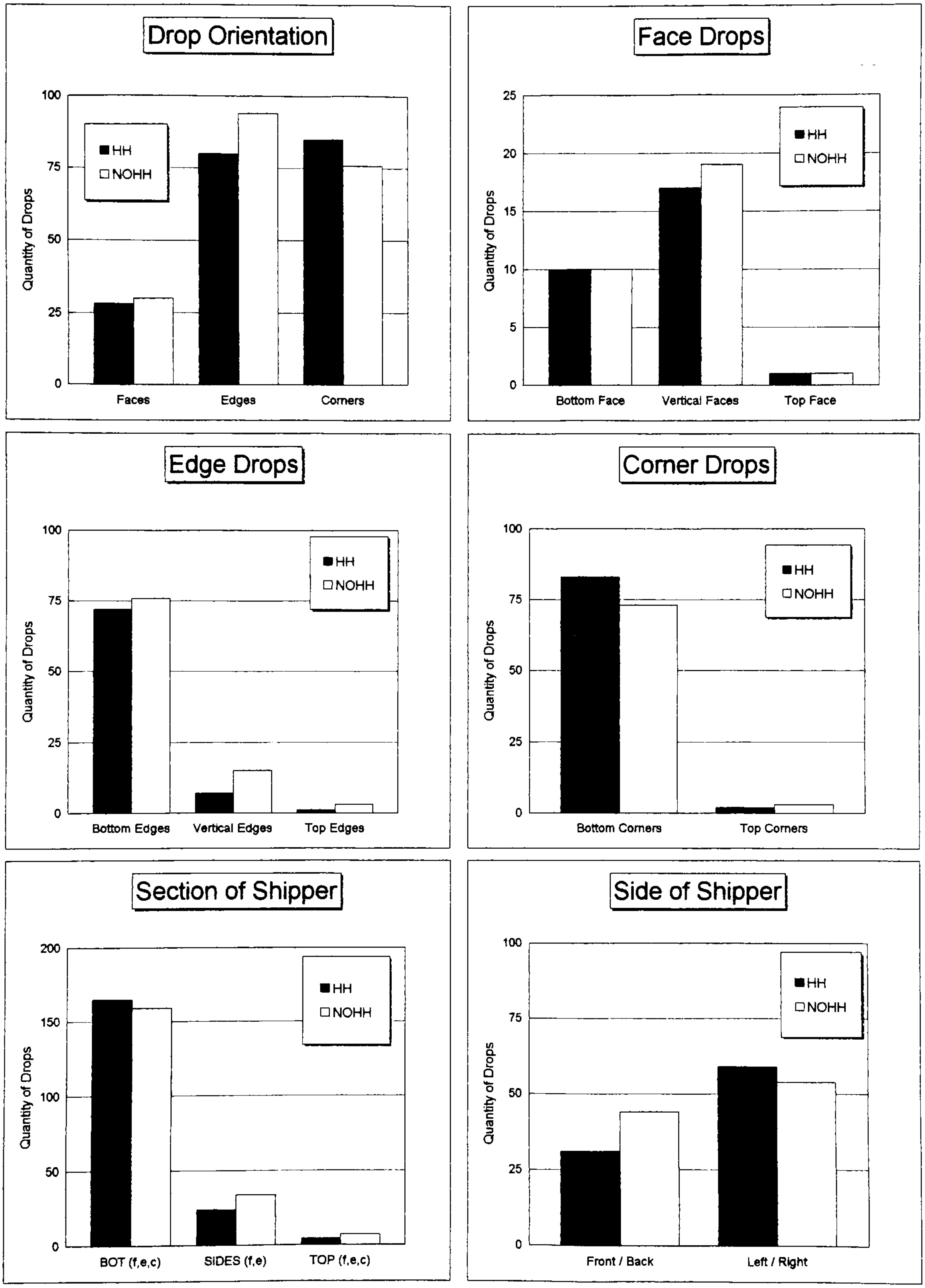
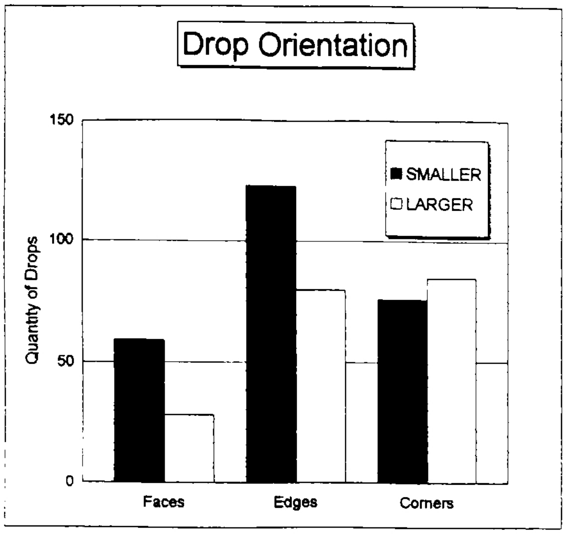
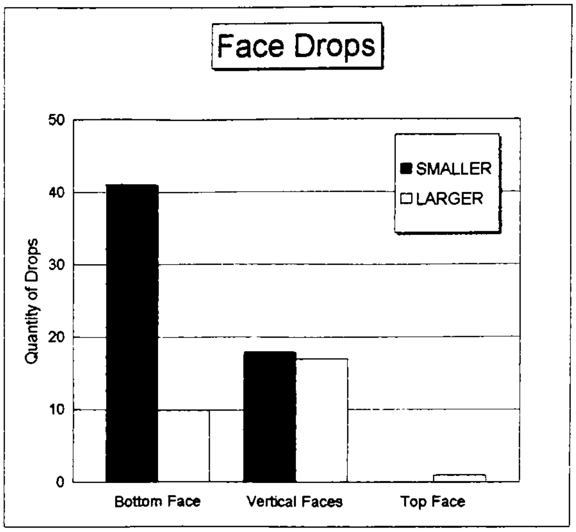
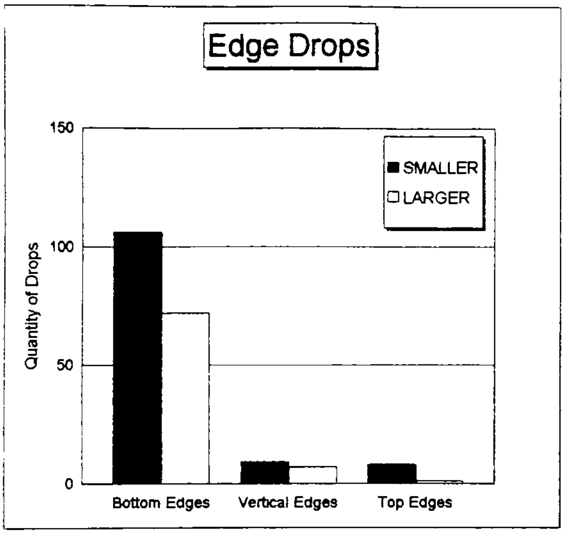
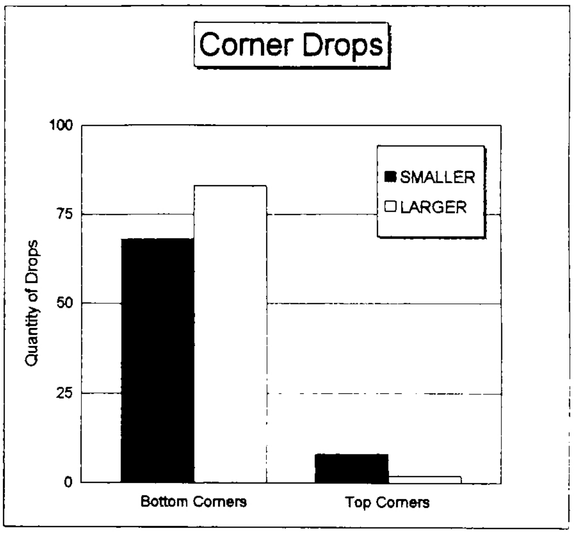


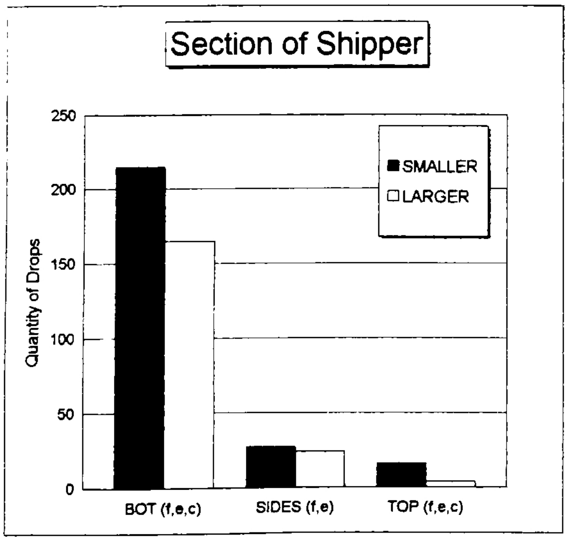
Figure C.5. (con't) Drop Orientation Distribution Charts (3 of 4)
Package Designs With Handholds











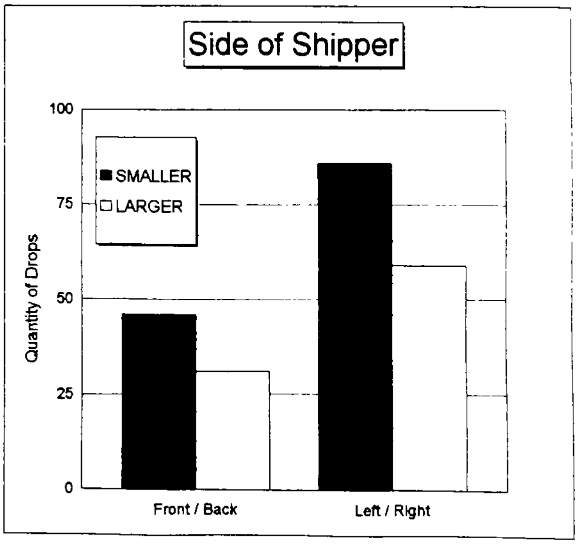


Figure C.5. (con't) Drop Orientation Distribution Charts (4 of 4)

Package Designs With NO Handholds

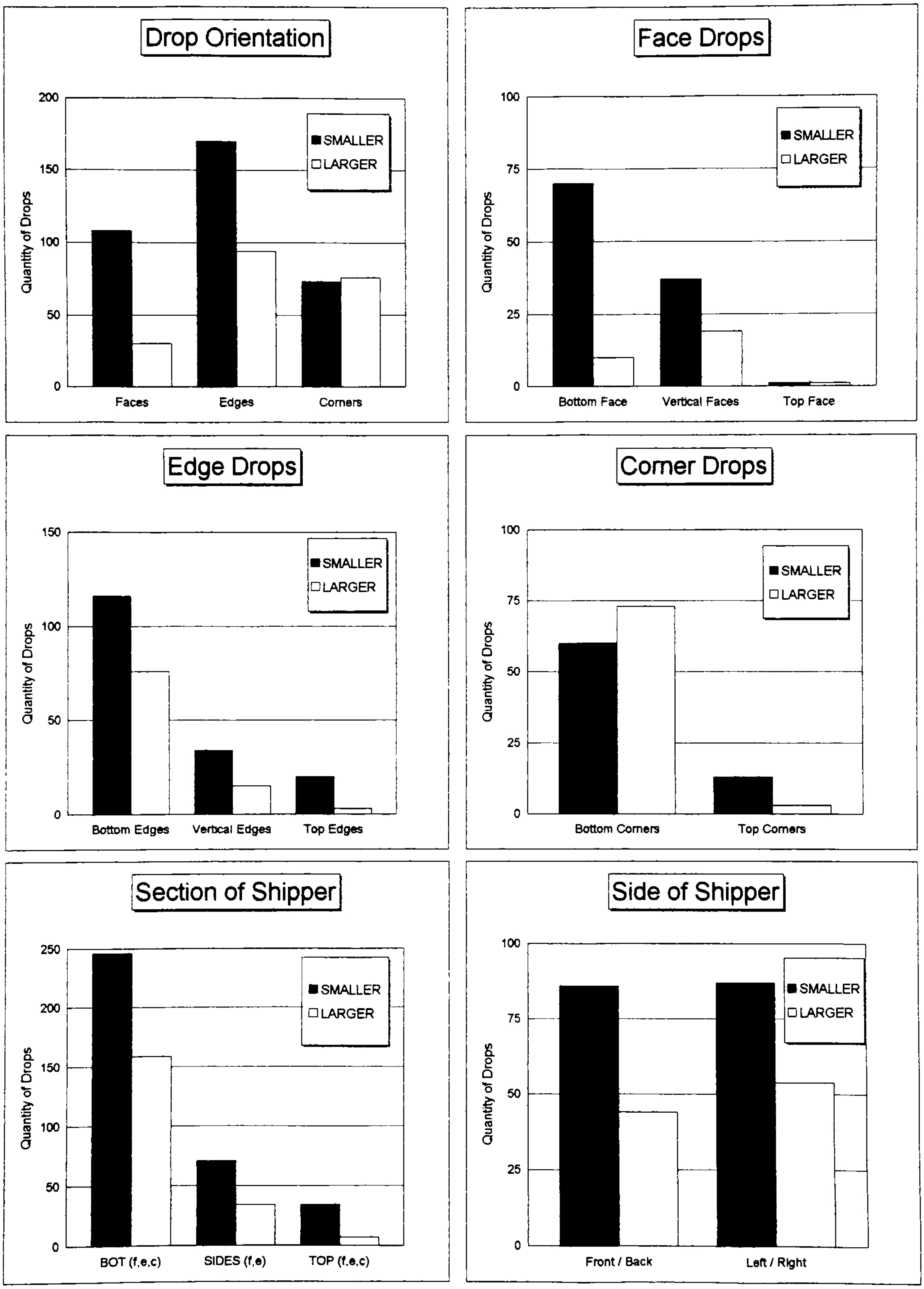


Figure C.6. Quantity of Drops by Drop Orientation Distribution for Package Size and Use of Handholds

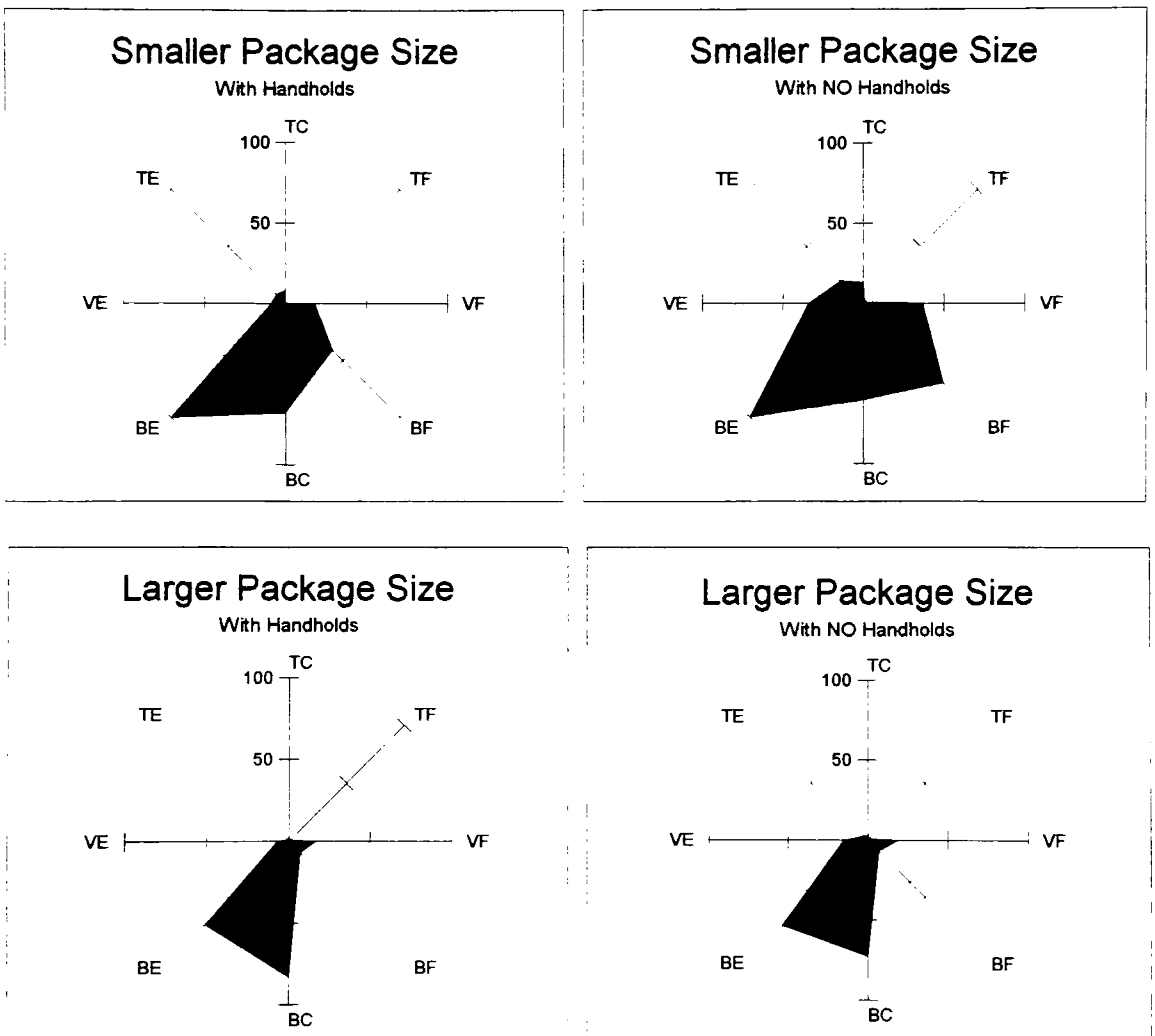
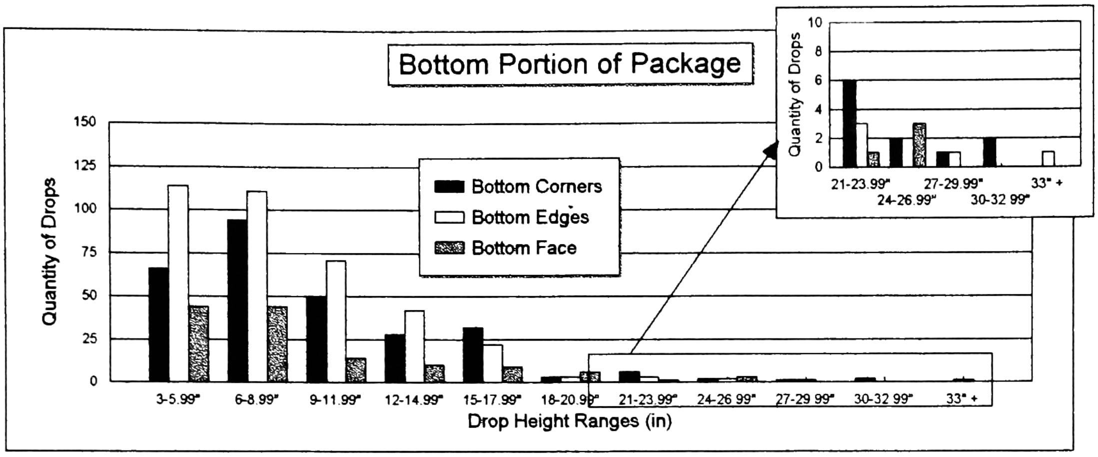
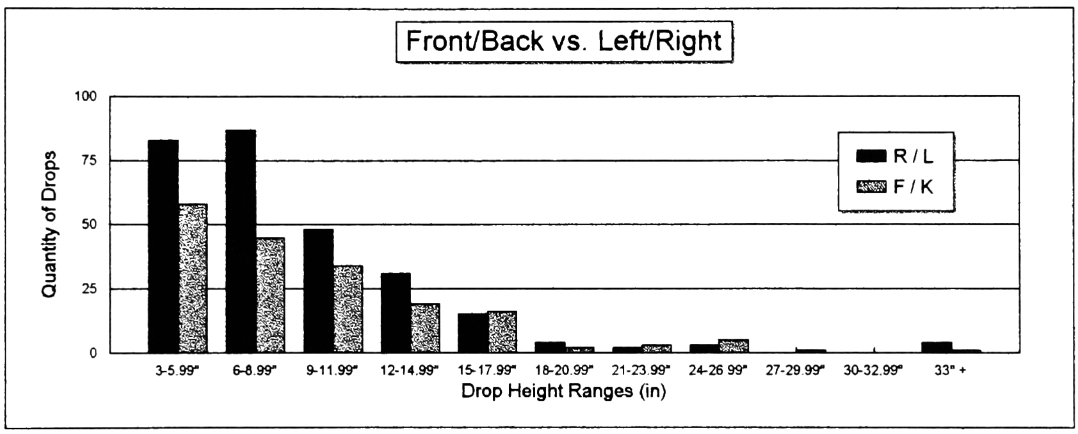
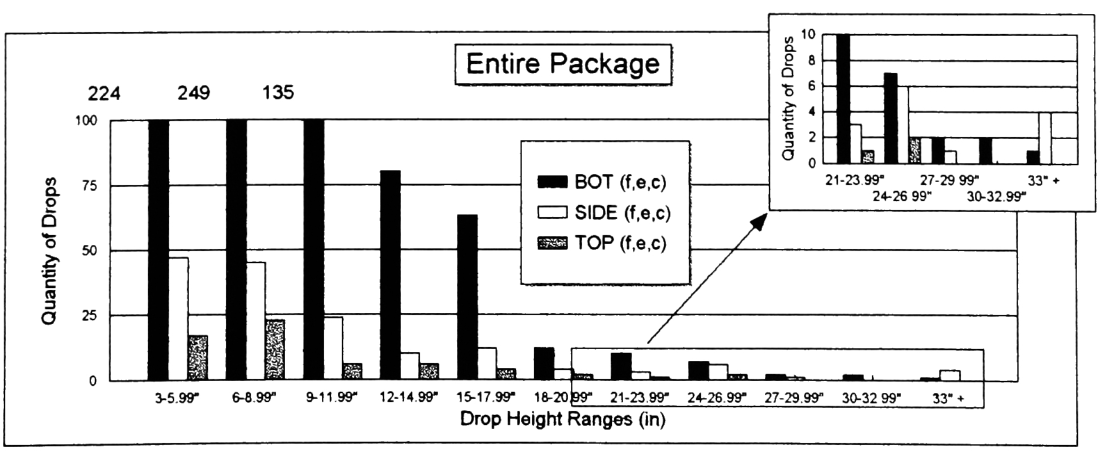


Figure C.7. Drop Height by Drop Orientation Distribution







Appendix D

Table D.1. Drop Orientation Distributions

ORIENTATION		PACKAGE SIZE SMALLER HH	SMALLER NOHH	LARGER HH	LARGER NOHH	TOTALS		% Total
CORNERS	BFL	19	12	20	15	66		
	BFR	18	10	18	17	63		BOTTOM
	BKL	19	19	17	20	75		CORNER
	BKR	12	19	28	21	80	284	28.34%
	TFL	2	3	2	2	9		
	TFR	1	5	0	1	7		TOP
	TKL	2	4	0	0	6		CORNER
	TKR	3	1	0	0	4	26	2.59%
EDGES	BF	12	16	14	17	59		
	BK	19	25	9	10	63		BOTTOM
	BL	39	42	18	30	129		EDGE
	BR	36	33	31	19	119	370	36.93%
	FL	2	9	2	4	17		
	FR	1	6	4	3	14		VERTICAL
	KL	2	10	1	4	17		EDGE
	KR	4	9	0	4	17	65	6.49%
	TF	4	7	0	1	12		
	TK	1	7	1	2	11		TOP
	TL	1	4	0	0	5		EDGE
	TR	2	2	0	0	4	32	3.19%
FACES	B	41	70	10	10	131	131	13.07%
	F	6	18	4	9	37		F / K
	K	4	13	3	5	25	62	6.19%
	L	5	3	8	3	19		L / R
	R	3	3	2	2	10	29	2.89%
	T	0	1	1	1	3	3	0.30%
		258	351	193	200	1002		100.00%

Table D.2. Drop Orientation Percentage of Occurrences

	SMALLER PACKAGE SIZE						LARGER PACKAGE SIZE					
	USE OF HANDHOLDS			NO HANDHOLDS			USE OF HANDHOLDS			NO HANDHOLDS		
Orientation	COUNT	TOTAL	% TOTAL	COUNT	TOTAL	% TOTAL	COUNT	TOTAL	% TOTAL	COUNT	TOTAL	% TOTAL
Faces	59	258	22.87	108	351	30.77	28	193	14.51	30	200	15.00
Edges	123	258	47.67	170	351	48.43	80	193	41.45	94	200	47.00
Corners	76	258	29.46	73	351	20.80	85	193	44.04	76	200	38.00
TOTALS	258	258	100.00	351	351	100.00	193	193	100.00	200	200	100.00
Bottom Face	41	258	15.89	70	351	19.94	10	193	5.18	10	200	5.00
Vertical Faces	18	258	6.98	37	351	10.54	17	193	8.81	19	200	9.50
Top Face	0	258	0.00	1	351	0.28	1	193	0.52	1	200	0.50
TOTALS	59	258	22.87	108	351	30.77	28	193	14.51	30	200	15.00
Bottom Edges	106	258	41.09	116	351	33.05	72	193	37.31	76	200	38.00
Vertical Edges	9	258	3.49	34	351	9.69	7	193	3.63	15	200	7.50
Top Edges	8	258	3.10	20	351	5.70	1	193	0.52	3	200	1.50
TOTALS	123	258	47.67	170	351	48.43	80	193	41.45	94	200	47.00
Bottom Corners	68	258	26.36	60	351	17.09	83	193	43.01	73	200	36.50
Top Corners	8	258	3.10	13	351	3.70	2	193	1.04	3	200	1.50
TOTALS	76	258	29.46	73	351	20.80	85	193	44.04	76	200	38.00
BOT (f,e,c)	215	258	83.33	246	351	70.09	165	193	85.49	159	200	79.50
SIDES (f,e)	27	258	10.47	71	351	20.23	24	193	12.44	34	200	17.00
TOP (f,e,c)	16	258	6.20	34	351	9.69	4	193	2.07	7	200	3.50
TOTALS	258	258	100.00	351	351	100.00	193	193	100.00	200	200	100.00
Front / Back	46	258	17.83	86	351	24.50	31	193	16.06	44	200	22.00
Left / Right	86	258	33.33	87	351	24.79	59	193	30.57	54	200	27.00
TOTALS	132	258	51.16	173	351	49.29	90	193	46.63	98	200	49.00

Table D.3. Drop Orientation Distributions

ORIENTATION		CARRIER A	CARRIER G	ROUTE CO	ROUTE MN	TOTALS		% Total
CORNERS	BFL	35	31	32	34	66		
	BFR	33	30	28	35	63		BOTTOM
	BKL	32	43	34	41	75		CORNER
	BKR	46	34	39	41	80	284	28.34%
	TFL	3	6	6	3	9		
	TFR	2	5	3	4	7		TOP
	TKL	5	1	3	3	6		CORNER
	TKR	2	2	1	3	4	26	2.59%
EDGES	BF	37	22	32	27	59		
	BK	30	33	29	34	63		BOTTOM
	BL	58	71	73	56	129		EDGE
	BR	42	77	71	48	119	370	36.93%
	FL	10	7	9	8	17		
	FR	9	5	9	5	14		VERTICAL
	KL	10	7	9	8	17		EDGE
	KR	8	9	10	7	17	65	6.49%
	TF	7	5	5	7	12		
	TK	6	5	5	6	11		TOP
	TL	3	2	3	2	5		EDGE
	TR	0	4	3	1	4	32	3.19%
FACES	B	63	68	56	75	131	131	13.07%
	F	21	16	17	20	37		F / K
	K	13	12	14	11	25	62	6.19%
	L	3	16	12	7	19		L / R
	R	4	6	7	3	10	29	2.89%
	T	2	1	2	1	3	3	0.30%
		484	518	512	490	1002		100.00%

Table D.4. Distribution of Drop Heights Per Given Orientations

Smaller Package Size

	WITH HANDHOLDS								
Drop Ht.	BOTTOM			VERTICAL SIDES			TOP		
(inches)	CORNERS	EDGES	FACE	EDGES	F / K	L / R	CORNERS	EDGES	FACE
3-5.99	21	37	19	3	5		1	2	
6-8.99	19	37	11	1	4	3	4	4	
9-11.99	16	17	3	3	1				
12-14.99	5	10	2	1			2	1	
15-17.99	7	2	6			2	1	1	
18-20.99		2		1		2			
21-23.99									
24-26.99		1				1			
27-29.99									
30-32.99									
33-35.99									
36-38.99									
39-41.99									
42-44.99									
45+									
	68	106	41	9	10	8	8	8	0

	WITH NO HANDHOLDS								
Drop Ht.	BOTTOM			VERTICAL SIDES			TOP		
(inches)	CORNERS	EDGES	FACE	EDGES	F / K	L / R	CORNERS	EDGES	FACE
3-5.99	15	39	20	13	12	1	3	8	
6-8.99	22	32	25	16	7	1	5	5	
9-11.99	7	25	9	4	4		2	2	1
12-14.99	5	9	5		3		2	1	
15-17.99	7	9	3		1		1	1	
18-20.99		1	4					1	
21-23.99	3		1		1			1	
24-26.99			3	1	2	1		1	
27-29.99	1	1							
30-32.99									
33-35.99						2			
36-38.99					1				
39-41.99						1			
42-44.99									
45+									
	60	116	70	34	31	6	13	20	1

Larger Package Size

	WITH AND WITHOUT HANDHOLDS								
Drop Ht.	BOTTOM			VERTICAL SIDES			TOP		
(inches)	CORNERS	EDGES	FACE	EDGES	F / K	L / R	CORNERS	EDGES	FACE
3-5.99	30	38	4	2	1	5	5	4	
6-8.99	53	42	7	2	2	8	3	3	1
9-11.99	27	29	6			2	4	2	1
12-14.99	18	23	1			3	4	1	
15-17.99	18	11	3				2	4	
18-20.99	3				1	2		1	
21-23.99	3	3	1				1		
24-26.99	2	1		1			2		
27-29.99									
30-32.99	2								
33-35.99									
36-38.99		1							
39-41.99									
42-44.99									
45+									
	156	148	22	5	4	20	21	15	2

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